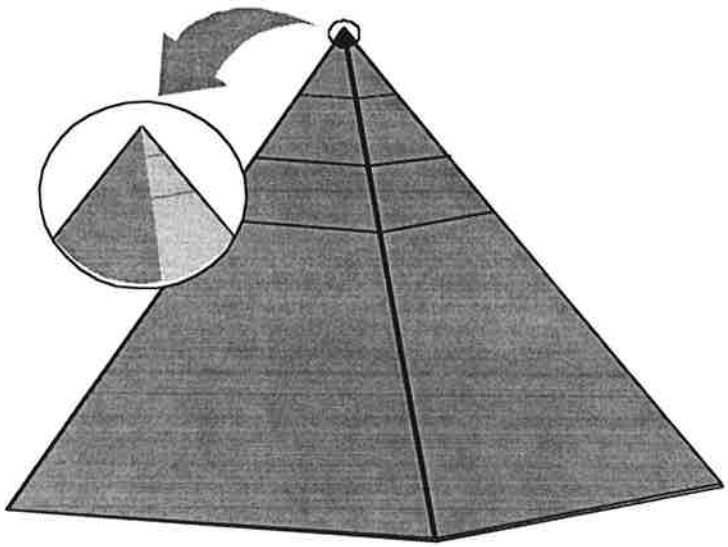
Proceedings

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INTERNATIONAL COOPERATION ON THEORIES AND CONCEPTS IN TRAFFIC SAFETY



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ICTCT and the Department of Traffic Planning and Engineering
Lund University, Sweden

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Context Model of Risk

1. Introduction

Since the time when psychologists began to endeavour to understand what risk actually was there have been developed many theories and concepts trying to elucidate its nature. Supposedly, it was the Wild's theory that made the greatest career[1]. It was in a mechanistic, simple way that it solved the phenomenon of risk undertaking; all psycho-physiological processes present in a chain reaction on the road were considered to be present here as if beyond the driver's. control. Similar, in a sense, was Klebelsberg's theory, which, taking into account dynamic environmental parameters, tried to assert close relations of interdependence between objective and subjective risk[2]. Undoubtedly enough, Fuller's. concept offered an unconventional approach to the problem of risk undertaking, there could be found a shade of philosophical thinking concerning the perception of the situations in road traffic as threat avoidance[3]. On the other hand, all that could possibly lead to the so called risk boiled down to the driver's. misjudgement of the situation, i.e. an entire cycle of processes on a mental level. No extreme psychologizing could be found here, as in this process of driving, risk evading, the parameters of speed and road itself played an important role. Botticher and Van Molen presented a completely different direction as well as the approach to the issue. These authors tried to view the problem of risk in a hierarhized and structural way, and the interpretation of risk undertaking as such by the drivers seems to be too mechanistic[4]. Making a simplified analysis of the above mentioned theories, it can be noticed that none of them explained the phenomenon of risk comprehensively. The psychologists involved with the issue of risk either excessively psychologized or ascribed too great an importance to the physical environment. And, although the recent SARTRE research aimed at a description to what degree social factors could influence risk undertaking on the road, the control of them was made extremely hard because of a very differentiated types of cars in various countries and dissimilar standards of road networks, etc[5]. So, in this aspect the comparative analysis is especially difficult, too.

2.Research undertaken

During my research for the last three years I observed quite interesting phenomenon, which would not be easy to interpret by referring to the existing theories. As a matter of fact, the same drivers seemed to present quite different levels of risk in different situations. In some circumstances they drove very carefully and paying attention in other, very dangerous ones, where the level of risk was so high that it would have been impossible to suspect them of misjudgement and underestimation of the endangerment. These observations inclined me to undertake experimental research which would allow for an interpretation of the phenomenon.. In order, however, to keep certain variables exactly under control, I had to limit the experiment itself to few controlled items.

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[1] Wilde G.J.S. *The Theory of Risk Homeostasis, Implications for Safety and Health*, "Risk Analysis" vol.2,no.4, p.209-225 (1982)

[2] Klebelsberg D. :*Das Modell der subjektiven und objektiven Sicherchelt*, "Schweizerische Zeitschrift fur Psychologie und ihre Anwendungen", Bd.36, s.285-294 (1977)

[3] Fuller R.: A conceptualisation od driving behaviour as threat avoidance, "Ergonomics" vol.27, p.1139-1155 (1984)

[4] Molen H.H.,Botticher A.M.T.: A hierarchical risk model for traffic participants, "Ergonomics", vol.31, no.4, p.537-555 (1988)

[5] SARTRE: *Social attitudes to road traffic risk in Europe*, Raport on principal aspects, June (1993)

That was the reason why I did not take into consideration such features as age, driving experience, education or place of living while choosing the sample. The sole reaction of drivers to certain situations on the road bore the only relevance to the research. I assumed that the level of risk, i.e. undertaking especially endangering behaviour, would ensue from the social context. Altogether 80 drivers in a variety of road situations were examined. The measurement of the size of risk among the bus drivers of Cracow's. Municipal Transport Enterprise was the experimental situation, and, driving without passengers was the control situation. Items scrutinised in both, experimental and control cases were those that would give evidence to risk undertaking. The reactions were as follows:

1 enforcing priority
2. abrupt braking
3. barring other drivers' way
4. driving across the crosswalk when there was green light for the pedestrians
5. careless driving across railway crossing
6.offences against speed limits

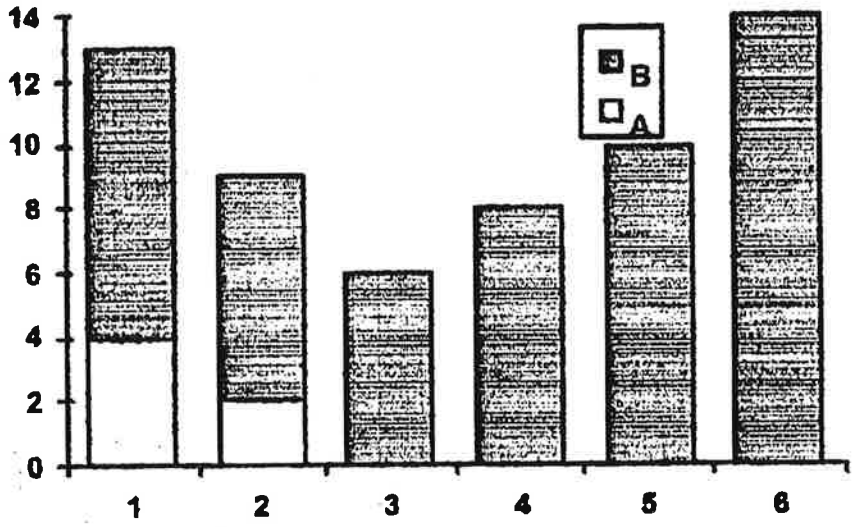
The extent of given reactions, preliminary considered to be dangerous in road traffic, compared for each driver in both - experimental and control - cases accounted for the level of risk. The research lasted eight months and took into consideration also weather conditions, time of the day and intensity of traffic.

3.The course of the experiment

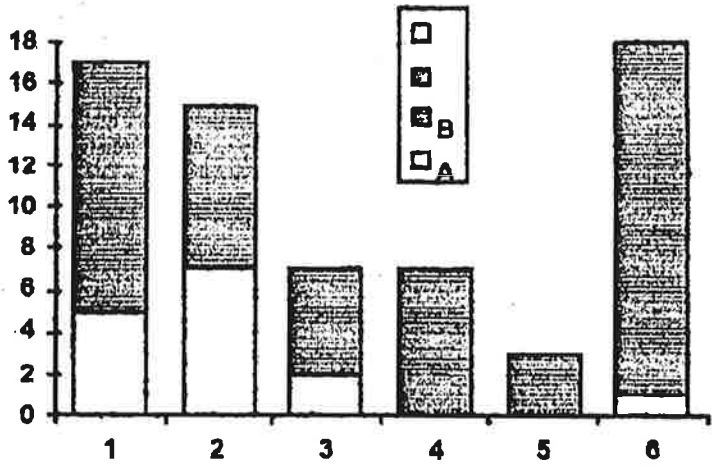
The procedures of the research were as further described. The experimentator was sitting on the driver's bus on a front seat and was closely watching the reactions chosen for the experiment and noted them on a special research sheet **(A)**. Technically speaking, the second part of the experiment was more difficult, when after the shift the drivers came to the depot **(B)**. They could have grown suspicious towards the passenger's (experimentator) staying in the car. Yet the differences in reactions were so significant that, even taking into account statistic error, they could be relied upon. Jointly, 80 drivers were examined.

4. Results

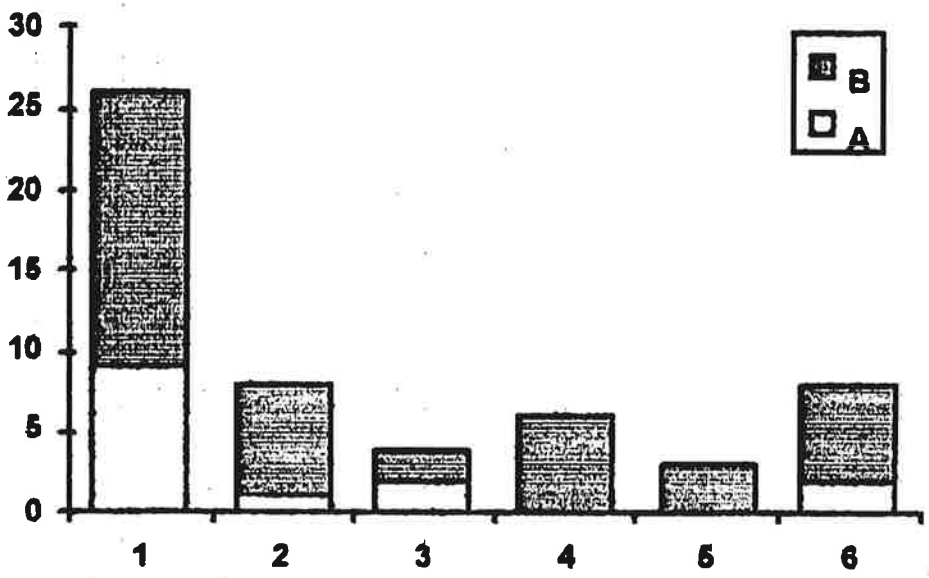
The results arrived at during the experiment have been compiled into the following diagrams:



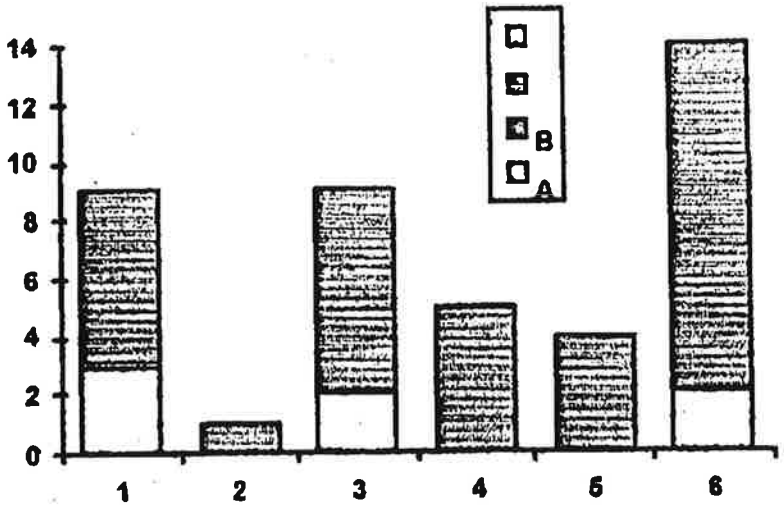
1.Comparative analysis of behaviour in Spring



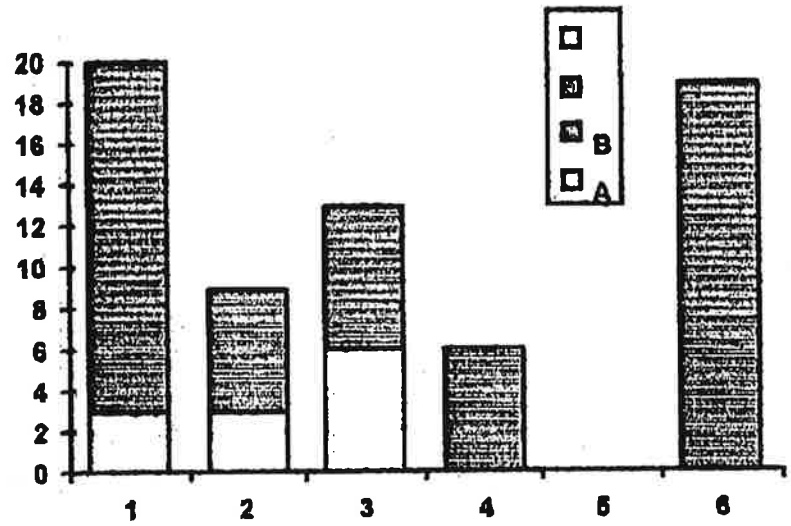
2. Comparative analysis of behaviour in Summer



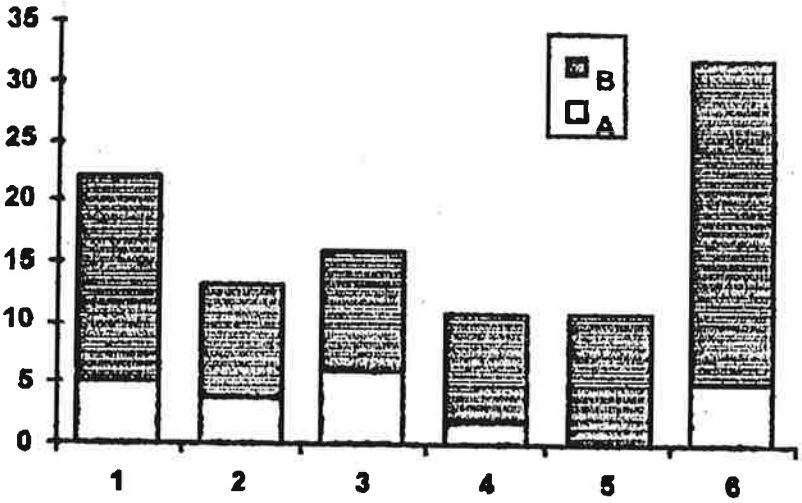
3. Comparative analysis of behaviour in Winter



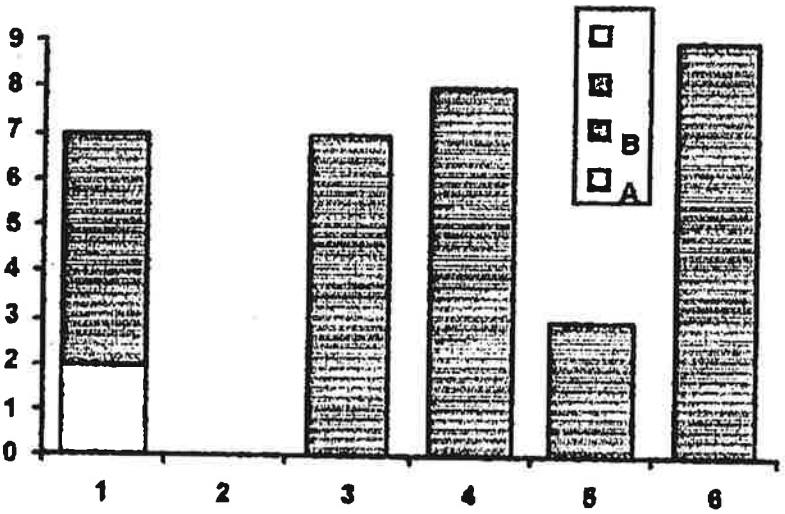
4. Comparative analysis of behaviour under unfavourable weather conditions



5. Comparative analysis of behaviour under favourable weather conditions



6. Comparative analysis of behaviour during very heavy traffic



7. Comparative analysis of behaviour during light road traffic

The achieved results present a paradox; the selfsame drivers, even during one day, manifested two extreme driving models: very reckless and exceptionally safe, even self-protective. This regularity was almost a rule. Surely enough, there were situations where the reckless driving manner was particularly distinct as, f.e. in heavy road traffic, under favourable weather conditions, on the other hand, in other conditions, f.e. in winter these differences were rather small, yet some regularity still appeared. Hence, it can be stated that we deal with a general regularity that drivers while at work as professionals tend to present more safe driving manner, whereas in other situations their behaviour is characterised by a much higher degree of risk.

5.Conclusions

During the analysis of the facts mentioned above there rose several questions about the main reason of so diametrically opposed behaviour. Undoubtedly, the social context is the criterion responsible. It is significant that, in the presented research the more influential the social context was the lower the level of risk was undertaken, and vice versa (Fig 1). It seems to me that the impact of

social context was so powerful that the drivers adopted more safe driving manner. In situation when such manner was no longer necessary they tended to undertake much higher risk. There arises yet another question, in the light of the facts presented, whether the situation in road traffic can take place without social contact. Definitely not, although some physical separation of the driver from the environment, due to the car's. construction, is behind the fact that the drivers limit the impact of social context to the interior of the vehicle. Of course, the influence of the social context inside a bus must be significant owing to the number of passengers, the question is what the situation would be like in a passenger car. I assume that a similar phenomenon can be found here as well. Results of some researches have proved that drivers prefer much more safe driving manner when there are other people in the car, particularly members of the family. Both positive and negative impact of the social context can be exerted on risk undertaking. This phenomenon is most explicitly observable among young drivers. The presence of other (also young) people in the car can fortify the tendency to speeding, enforcing priority, drunk-driving, in a specific way. In this case the social context only makes the dangerous behaviour - thus risk - stronger. It can be especially high among drivers who prefer hazard.

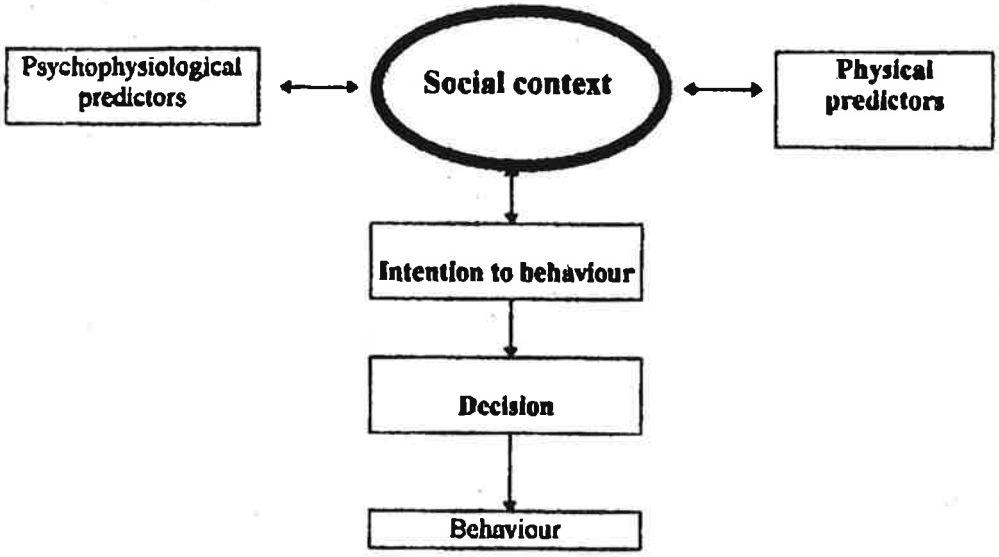


Fig. 1. Context model of risk

It is far from easy to evaluate, in the context of the research presented here, the extent to which the social context influences the level of risk undertaken in comparison with other variables, f.e. psychological ones: motivation, wrong decision making, stress etc. On the other hand, it would be extraordinarily difficult to state the power of these factors' impact. Needless to say, the social context ensues, to a great extent, from cultural influence. Undoubtedly, it would be very interesting to make an analysis of risk on roads taking into account the social context of various cultures.

Drivers' Perception of Pedestrians

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1. Introduction

Three different perspectives can be taken in investigating the interaction between various road users:- (a) an attempt can be made to observe or film the whole scene, usually from a distance and from above, so that it is in principle possible to trace the development of conflicts and how they are resolved; (b) a position at ground level can be selected close to the point of crossing or the pedestrian can be tracked as s/he proceeds across the road; and (c) a view can be taken from inside the vehicle by the driver, by an observer/passenger or by video recording. Both studies to be reported take the latter perspective and try to integrate the information from all three sources.

Objective data for each drive of an urban route was obtained by videofilming and human observation to allow for limitations of view with each technique. Videofilming had a further use in the second study as a prompt for drivers to give accounts of the problems they encountered and strategies they adopted during their drive. Interviewing drivers immediately after completing their drive can be time consuming but it has been shown in the context of motorway driving and on primary distributor roads (Saad, 1996a) that these verbal report techniques are effective in eliciting a detailed subjective view of events that can then be directly compared with the objective data.

The reactions of drivers to the successive events they encounter can be regarded as a function of the incoming information they process (attention), their accumulated experience (memory) and the criteria they apply to control the vehicle (decision making). If they are unaware of or decide to ignore relevant information, the probability of conflicts or accidents involving other road users is likely to increase. In particular, since it provides the base for subsequent processing, the content and sequence of visual search may be critical in allowing the driver sufficient time to react in an emergency. The laboratory study of the processes of visual search can be traced to the experiments of Neisser (1963) and are more recently summarised by Rabbitt (1984). In this context search is defined as an active interrogation of a scene from which drivers can very quickly decide where to look first and in what sequence to look for further information. It is predicted that the more experience they have, the better they will be able to optimize their scanning strategies and improve their speed of detection of relevant information.

One salient question thus concerns how well drivers process incoming information about pedestrian behaviour. It may be that such information is well processed but disregarded or that insufficient processing occurs in relation to the demands for very rapid reaction to emerging conflicts with pedestrians. Morever, they may be important differences related to the age, experience and gender of the driver. A large cohort study by Forsyth et al. (1995) indicated a much increased risk of accident for young male drivers in the first two years after passing their test. However, casualty figures involving pedestrians by age of driver are not easily available and are not often reported. Evans (1991), using FARS data, shows very large age and gender differences of driver threat to other road users but their interpretation is complicated by variable levels of exposure and that accidents may not be proportional to the annual distance travelled (Maycock et al., 1991).

2. Method

2.1 Study A

The focus of the relevant part of the first study was a route of 36km., chosen to include a wide range of conditions found on urban roads in the UK. The 207 drivers who lived on or close to the route were split into twelve age groups by age and gender. They were asked to give ratings of perceived risk on a ten-point scale at up to 147 specific locations and there were two in-car observers. In order to remove unwanted variation related to individual drivers preferring to use higher or lower parts of the scale, the data were standardised to express the different risk ratings in standard deviations from a mean set at zero (MSR). Full details can be found in the report by Carthy et al. (1993).

2.2 Study B

The second study that is still underway involves a sub-section of the initial route (13km.) selected to maximise the extent of pedestrian interaction at locations within the City Centre and other areas close to a hospital, the University of Newcastle and a local shopping area. The intention is to complete 80 drives of the route by male drivers aged between 17 and 30. Two types of objective data are collected for each drive (i) a videorecording using a Sony Handycam Hi8 fitted with a wide-angled lens and (ii) drive records completed by an in-car observer that particular focus on relevant events outside the range of the camera. The drive forms the first phase of the test session followed after a short break by the interview phase when the videorecording is replayed on a large colour TV screen (59 x 59 cm) in order to facilitate the driver's recall of incidents at specific locations. The system allows for S-VHS quality feedback using Hi8 quality camcorder cassettes.

The techniques for assisting subsequent verbalisation are based on the work of Leplat and Hoc (1981) and make it possible to prompt with the precise conditions that led to particular decisions. Responses to a set of standard questions, with opportunities for elaboration when necessary, were recorded by the interviewer and an audiotape was

made in order to allow more detailed analysis of selected incidents. In particular, this made it possible to compare objective and subjective data across specific locations and also to develop case studies for individual drivers.

3. Results

3.1 Study A

In the first study the accident data for each location were correlated with the mean risk ratings and there was a moderate level of correlation ($r = 0.42$, $p < 0.0002$). A more detailed analysis of the accident data separated the type of road user into vehicles, cyclists and pedestrians and whether accidents that resulted from driving in the same direction as the drivers

In the table of correlations below A = Motor vehicles; B = Pedestrians; C = Cyclists;
1 refers to the same direction of driving the route and 2 refers to any other direction.

	A1	**A2**	**B1**	**B2**	**C1**	**C2**	**Total**
MSR	0.41	0.37	0.04	0.09	0.30	0.24	0.42

So the risk ratings were predictively accurate in the case of vehicle-vehicle accidents but the same ratings were poor predictors of pedestrian-vehicle accidents. A multiple regression analysis, carried out to clarify which particular characteristics most influenced the drivers' perception of risk, showed that competing traffic flow was the most important factor and that competing pedestrian activity was one of the factors that had no significant effect. Because other vehicles pose the most potent source of threat and driving is regarded to some extent as a competitive activity, it is not surprising that the number and position of other vehicles should contribute very significantly to ratings of risk. More competitive driving behaviour was associated with younger drivers, both male and female.

3.2 Study B

The data for 40 out of the 80 drivers in the current study have been coded and illustrative descriptive analysis of two types are presented with respect to
(i) categorising the drivers according to their awareness of pedestrians and
(ii) frequencies of pedestrian detection at City Centre locations by all drivers.

Initially the proportion of times drivers specified at interview they had taken into account the potential or actual crossing behaviour of pedestrians at up to 20 specific locations on the route was analysed to separate drivers into three categories of awareness of pedestrians: low, medium and high as follows:
Low = 4 (0.25 or less); Medium = 31 (0.26 to 0.74); High = 5 (0.75 or more)

The details of the age, years of driving experience and the pedestrian awareness proportion (for 12-18 locations where pedestrians were involved in crossing) for each of the 9 male drivers in the low and high groups are shown below.

LOW	Age	Years' Experience	Detection Proportion
	18	0-1	0.167
	18	1-2	0.167
	17	0-1	0.200
	18	1-2	0.250
HIGH			
	18	0-1	0.786
	20	2-3	0.867
	26	3+	0.923
	19	2-3	0.929
	23	3+	1.000

Further analysis of the locations where the low awareness group failed to detect pedestrians showed that almost all the instances involved traffic signals whereas, at the fewer locations when drivers specified that pedestrians had affected their driving decisions, there were no signals. This suggested an analysis to check whether failure to detect pedestrians generally related to age and lack of experience. The following are typical of the relationships at City Centre locations with traffic signals but it will be necessary to complete the remaining drives before levels of statistical significance can be properly assessed. Yes/No refer to whether or not drivers indicated that they were aware of pedestrians at each location.

Location: Central Railway Station Crossing

		Yes	No
Age	17-20	8	14
	21-30	10	3
Experience			
Year	0-1	2	6
	1-2	6	6
	2-3	1	2
	3+	9	3

Location: City Centre Pedestrian

		Yes	No
Age	17-20	7	15
	21-30	7	7
Year	0-1	2	6
	1-2	3	8
	2-3	2	3
	3+	7	5

The proportions clearly change in relation to driver's age and experience which are necessarily correlated. However, a tentative conclusion is that the greatest difficulty in scanning for pedestrians occurs during the year immediately after passing the driving test.

4. Discussion

If a pedestrian accident or conflict with a vehicle is viewed in terms of a number of necessary conditions being fulfilled, failure by a driver to react to the pedestrian in time to take evasive action can be regarded as one critical component. There are numerous

examples from the videotapes in Study B, particularly the low awareness drivers, indicating that avoidance of a serious conflict or an accident was probably beyond the driver's control and depended on the pedestrian stopping crossing or taking some other form of evasive action.

Some researchers have proposed that these difficulties are likely to arise when drivers have to process rapid changes in the road environment and have emphasised the effects of overloading the capacity for processing information. However, the evidence from the comparisons between the low and high pedestrian awareness groups suggest that less exceptional circumstances may result in pedestrian accidents if the driver fails to scan for their presence. The high awareness group are characterised by their anticipation of potential problems, eg. masking by other vehicles or tendencies for pedestrians to behave in unexpected ways, and in some cases can link these concerns explicitly with specific parts of a location to check. In similar conditions the low awareness group make little or no mention of pedestrians.

Compared with the early demonstration of visual search strategies in tasks like proof reading, scanning the road environment is clearly more complex since many of the components are dynamically changing their speed and position, while others are static
but contain relevant information. However, the difficulty of the driving task makes it likely the effects of practice and experience will be even greater. Study A implies that many drivers are predisposed to pay particular attention to other vehicles because of the threat they pose, and that they take far less account of vulnerable road users. Study B links lack of awareness of pedestrians more specifically to limited search strategies because of a tendency to concentrate too much on the state of traffic signals, at least in the case of young male drivers.

More generally, if inexperience is related to limitations in visual search strategies, there will be implications for other types of driving where unpredictable sources of information, like pedestrians in urban environments, are not effectively scanned. Saad (1996b), who employed similar procedures to Study B, tested novice drivers on motorways and examined problems with the lane change manoeuvre. She suggests that difficulties arise in distributing attention between current positional information that is dynamically changing and predicting future movements of other vehicles. She cites the example of a novice driver pulling into the central lane without noticing another vehicle seeking to occupy it from the other direction.

If restricted visual search patterns can be shown to operate widely, there are clear implications for driver training. It would be preferable during training to include practice of the skills required to develop rapid scanning of appropriate sources of information, especially the more unpredictable ones, than to leave them to be self-taught by experience after passing the driving test.

5. Acknowledgements

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We are also happy to acknowledge the assistance of Duncan Knox in conducting the drives and interviews, and Kathryn Toner with the coding and analysis of the data. Discussion with Farida Saad at INRETS contributed considerably to the development of the methodology and our analysis of the role of experience.

6. References

Carthy, T., Packham, D., Rhodes-Defty, N., Salter, D. and Silcock, D. (1993) Risk and Safety on the Roads: Perceptions and attitudes. AA Foundation for Road Safety Research, Basingstoke, Hants, UK.

Evans, L. (1991) Traffic Safety and the Driver. New York: Van Nostrand Reinhold.

Forsyth, E., Maycock, G. and Sexton, B. (1995) Cohort study of learner and novice drivers: Part 3, Accidents offences and driving experience in the first three years of driving. TRL Report PR111, Crowthorne, Berks, UK.

Leplat, J. and Hoc, J.M. (1981) Subsequent verbalisation in the study of cognitive processes. Ergonomics, 24, 713-755.

Maycock, G., Lockwood, C.R. and Lester, J. (1991) The accident liability of car drivers. TRL Report RR315, Crowthorne, Berks, UK.

Neisser, U. (1963) Decision time without reaction time: experiments in visual scanning. American Journal of Psychology, 76, 376-385.

Rabbitt, P. (1984) The control of attention in visual search. In R. Parasuraman and D.R. Davies (Eds.) Varieties of Attention. Orlando, USA: Academic Press.

Saad, F. (1996a) Contribution of observation and verbal report techniques to an analysis of situations and drivers' activity. Paper presented at the International Conference on Traffic and Transport Psychology, Valencia, Spain

Saad, F. (1996b) Driver strategies in car following situations. In A.G. Gale et al. (Eds.) Vision in Vehicles V. Amsterdam: Elsevier.

Two tools for finding what function links the dependent variable to the explanatory variables.

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Abstract

When the regression constants of a multivariate statistical model are correctly estimated, but its functional form does not match the phenomenon at hand and important explanatory variables are missing, the result can not be trusted to predict what will be the effect on the dependent variable of a change in an explanatory variable. We have good tools to estimate regression parameters but insufficient tools to choose what functional form fits a phenomenon and what explanatory variables need to be introduced into the model equation. The aim of this paper is to suggest two tools capable of guiding what an appropriate functional form for the model equation should be and whether a candidate explanatory variable promises to be useful. Both tools are based on the idea that cumulative (integral) functions may reveal order where atomic presentations of the same data fail. The example to which these tools are applied is the modeling of accident frequency for two-lane rural roads in Maine. The domain of application of the tools is general.

1. Introduction.

Multivariate statistical modeling is a popular tool of science and engineering. Its purpose is to discover useful regularities in observed data and to cast these into the form of model equations. In this manner one aims to separate the random and unexplained part of a phenomenon from the part that is systematic and useful for predictions of interest. This paper has been motivated by interest in finding the equation that expresses average accident frequency (the dependent variable) as a function of traffic flow, traffic control, and road features (the explanatory variables). While the context here is specific, the methods discussed are general and may apply equally to, say, multivariate statistical models of transportation demand, pavement distress, weather change, or educational achievement.

The sought model equation consists of three elements:

1. symbols of one kind (usually written in uppercase Latin) which represent the *explanatory variables*;
2. symbols of another kind (usually written in lowercase Greek) which represent the *regression constants*; and,
3. *operators* (addition, multiplication, exponentiation, log-function and other signs).

The manner in which the operators link the symbols into a mathematical sentence determines the *functional form* of the model equation. Thus, for instance, the sentence, $Y=\alpha+\beta X_1+\gamma X_2$, is linear (additive) in form with two explanatory variables and three regressions constants; the sentence $Y=\alpha X_1^{\beta}X_2^{\gamma}X_3^{\delta}$ is multiplicative in form, with three explanatory variables and four regression constants. The latter sentence may be made linear by a logarithmic transformation and can be referred to as Log-linear.

In the course of modeling, the modeler will make two major decisions:

a. What explanatory variables to include in the model equation; and,
b. What its functional form should be.

Once these decisions are made, it is possible to use data to estimate the values of the unknown regression constants. Methods for estimating regression constants are well developed; the means for doing so - the software packages - are ubiquitous; and the act of estimation is therefore routine and easy. Although statistical software packages can also be used to decide which explanatory variables to keep or introduce into the model, the methods (e.g. stepwise regression) used for doing so are much less definitive than those used for the estimation of regression constants. Finally, there is no general theory, method or software for determining what the functional form of the model equation should be.

Unfortunately, if the correct functional form has not been chosen for the model equation and/or if the appropriate explanatory variables are not used, the entire edifice on which the method for estimating regression constants rests crumbles into meaninglessness. Suppose, for example, that Y represents the frequency of single-vehicle accidents, X traffic volume, and that the correct functional form is $Y=\alpha X+\beta X^2$ with $\beta<0$. If the modeler decided to use the linear model form $Y=\gamma+\delta X$, estimates of the regression constants γ (the intercept) and δ (the slope of the line) are easily obtained. One can even estimate their standard error. However, there is in reality no intercept γ since the correct model starts from the origin, nor does the slope δ relate to anything

in the correct model. Naturally, there is no meaning to the standard error of estimates of such phantom regression coefficients. One can only speak about the estimate of a regression coefficient and of its precision, if the modeled phenomenon is in accord with the chosen functional form. Conversely, if the functional form that is used is inappropriate, the regression coefficients obtained have no clear meaning and there is little interest in their estimated value or precision.

In spite of its pivotal role in multivariate statistical modeling, the tools of search for an appropriate functional form are, at present, much less developed than the tools for estimating regression constants. One tool for identifying the appropriate variables and functional form is *exploratory data analysis*. Here one examines the data in visual representations, by cross-tabulations, by correlations and by similar means. Another way of performing the task is by examining the goodness of fit for a large number of candidate functional forms. Finally, the opportunity exists to improve on model functional form when, after the regression coefficients have been estimated, the 'residuals' are examined. We find however, that the data used are often so complex, sparse and noisy, that exploratory data analysis can seldom go beyond the discernment of the existence of some joint drift or covariation. The same traits of the data will ensure that (keeping the same explanatory variables) different functional forms will have similar measures of goodness of fit. This makes discernment amongst alternative model forms unclear. The problem is compounded by the groundless habit of regarding the linear form in some undeclared sense simpler than alternative forms. In addition, goodness of fit usually improves with the introduction of additional explanatory variables and it is difficult to know when "overfitting" begins. Finally, when data is multidimensional and noisy, plots of residuals also tend to be so noisy as to be uninformative.

The difficulties of identifying the appropriate functional form exert a crippling effect on the activity of multivariate statistical modeling. The tendency is to use for most phenomena the "simplest" functional forms - linear or log-linear - since data seldom give a clear indication that a more elaborate functional form is called for. Inasmuch as phenomena of nature and society are seldom so simple (except for a very narrow range of values of explanatory variables), the resulting models tend to be disappointing in the success of their predictions and poor in the correctness of their explanations.

In this paper we aim to:

1. Improve on our ability to recognize the suitable functional forms by which an explanatory variable needs to be introduced into the model during the exploratory data analysis stage;
2. Provide improved means to recognize whether a chosen functional form is in fact satisfactory during the "examination of residuals" stage;
3. Provide improved means to determine whether and in what form should additional variables be introduced into the model during the examination of residuals stage.

The exploratory data analysis and also the examination of residuals require the recognition of patterns. Unfortunately, data points and their residuals often present themselves in such amorphous clouds that the recognition of regularity is difficult. The **Integrate-Differentiate (ID)** method described in section 2, has been devised to facilitate the recognition regularity in exploratory data analysis. Its main idea is that patterns are clearer when data is presented in its accumulated form. The same idea is at the root of the CURE method, for the examination of **Cu**mulative **Re**siduals described in section 3.

2. The Integrate-Differentiate (ID) method for recognizing a suitable functional form.

The ID method is illustrated for the one-explanatory variable case. In the illustration, we seek the functional form relating the expected accident frequency to traffic flow. Figure 1 shows a scatterplot of accident data for some 1796 rural, two-lane, 0.05 mile long, homogeneous road sections in Maine. The abscissa of each point is the Average Annual Daily Traffic (AADT) for the road section in three years and the ordinate is the count of single-vehicle accidents recorded on that road section in the same three-year period. A grand total of 108 single-vehicle accidents occurred on these road sections in three years. The vast majority of road sections had no accidents, some had one, and a few recorded two accidents. If there is some systematic association between traffic flow and average accident frequency, it is certainly not discernible in Figure 1.

We will now use the same data to draw the ***Empirical Integral Function*** as follows. For each road section determine its AADT *bin-width*. The left boundary of the bin is half-way to the nearest lower AADT and the right boundary of the bin is half-way to the nearest higher AADT. Therefore the bin-width is the difference between the nearest higher and nearest lower AADT divided by two. The bin height is the accident count of the road section or, if several section

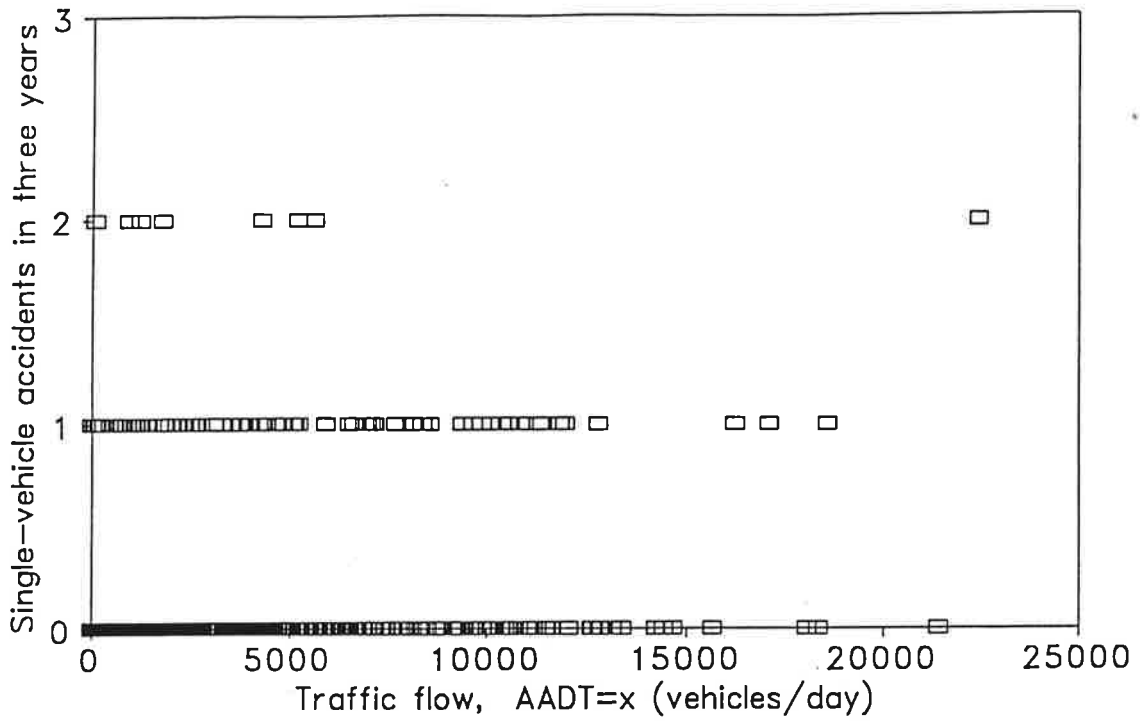


Figure 1: Single-vehicle accidents in three years versus average traffic flow for 1796 road sections of 0.05 miles long.

have the same AADT, their average accident count. The value of the Empirical Integral Function at the right boundary of the bin is the sum of all bin areas from the lowest AADT up to that boundary. The Empirical Integral Function, $F_E(X)$, for the data in Figure 1 is shown in Figure 2. It is evident that the apparently patternless data in Figure 1 have been rearranged so as to reveal some order.

To explain the essence of Figure 2, assume that there exists a function $\kappa=f(x)$ linking the expected accident frequency, κ, and the Annual Average Daily Traffic, x. The definite integral of $f(x)$ from $x=0$ to $x=X$, i.e., the area under the curve $f(x)$, will be called the ***Integral Function***, $F(X)$. The summation of bin areas which gave rise to the ***Empirical Integral Function***, denoted by $F_E(X)$, is an estimate of the same area. Thus, the $F_E(X)$ is an estimate of $F(X)$. If the functional form of $F(X)$ can be recognized by examining the Empirical Integral Function $F_E(X)$, then the functional form of $f(x)$ follows as the derivative of $F(X)$. The main idea of the ID method is that one can fruitfully speculate about the functional form behind the Empirical

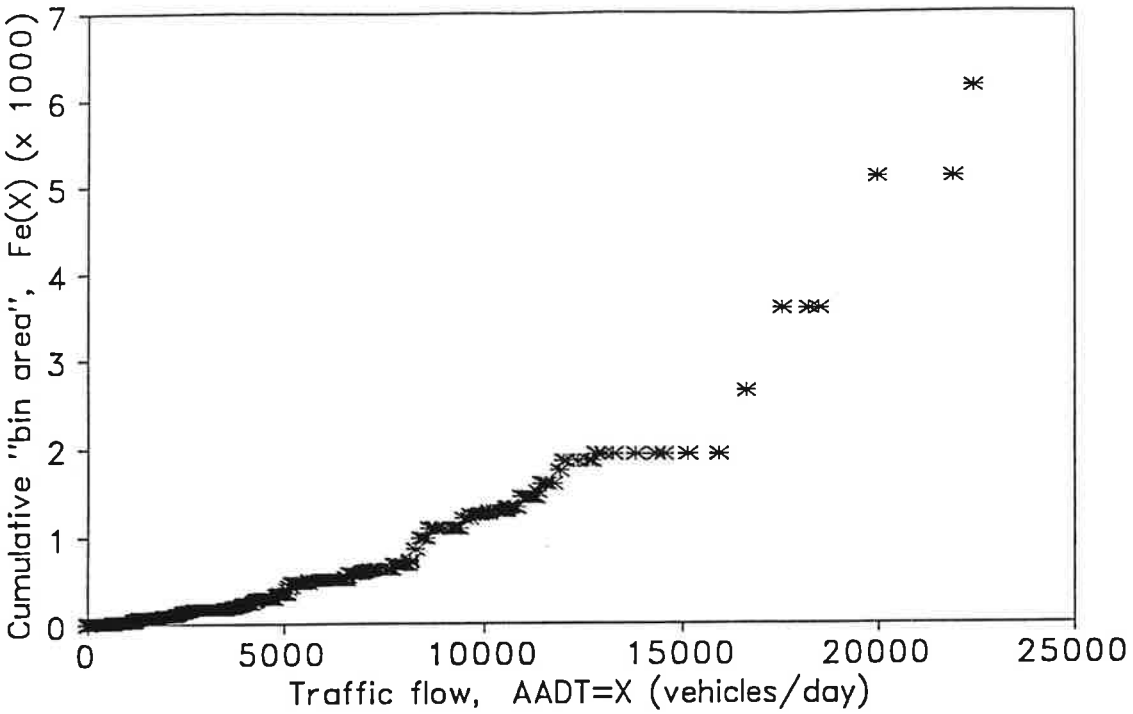


Figure 2: The Empirical Integral Function for the data in Figure 1.

Integral Function even when the raw data shows no discernible pattern. Graphical illustrations of some candidate Integral Functions are shown in Figure 3. The order created by the cumulation of bin areas may be partly illusory since many cumulative curves look similar. However, some discernment is already possible. Thus, for instance, were the expected accident frequency κ a constant that does not depend on AADT, then $F(X)$ would be a straight line through the origin. This is surely not the case here.

If $\kappa=f_1(x)=\alpha x^{\beta}$ then $F_1(X)=[\alpha/(\beta+1)]X^{\beta+1}$. As shown in Figure 3, this is a candidate function but only if $\beta>1$. If $f_2(x)=\alpha x+\beta x^2$ then $F_2(X)=(\alpha/2)X^2+(\beta/3)X^3$. This functional form can reproduce the point of inflection when $\beta<0$. However, since no decrease in slope is indicated in Figure 2, $\beta>0$ seems appropriate here. This is probably the farthest that discernment by inspection of the Empirical Integral Function can go.

Whether F_1 or F_2 fit the data better can be determined relatively simply. If F_1 is suitable, then plotting $\log[F_E(X)])$ against $\log(X)$ one should see a straight line with $\log[\alpha/(\beta+1)]$ as intercept

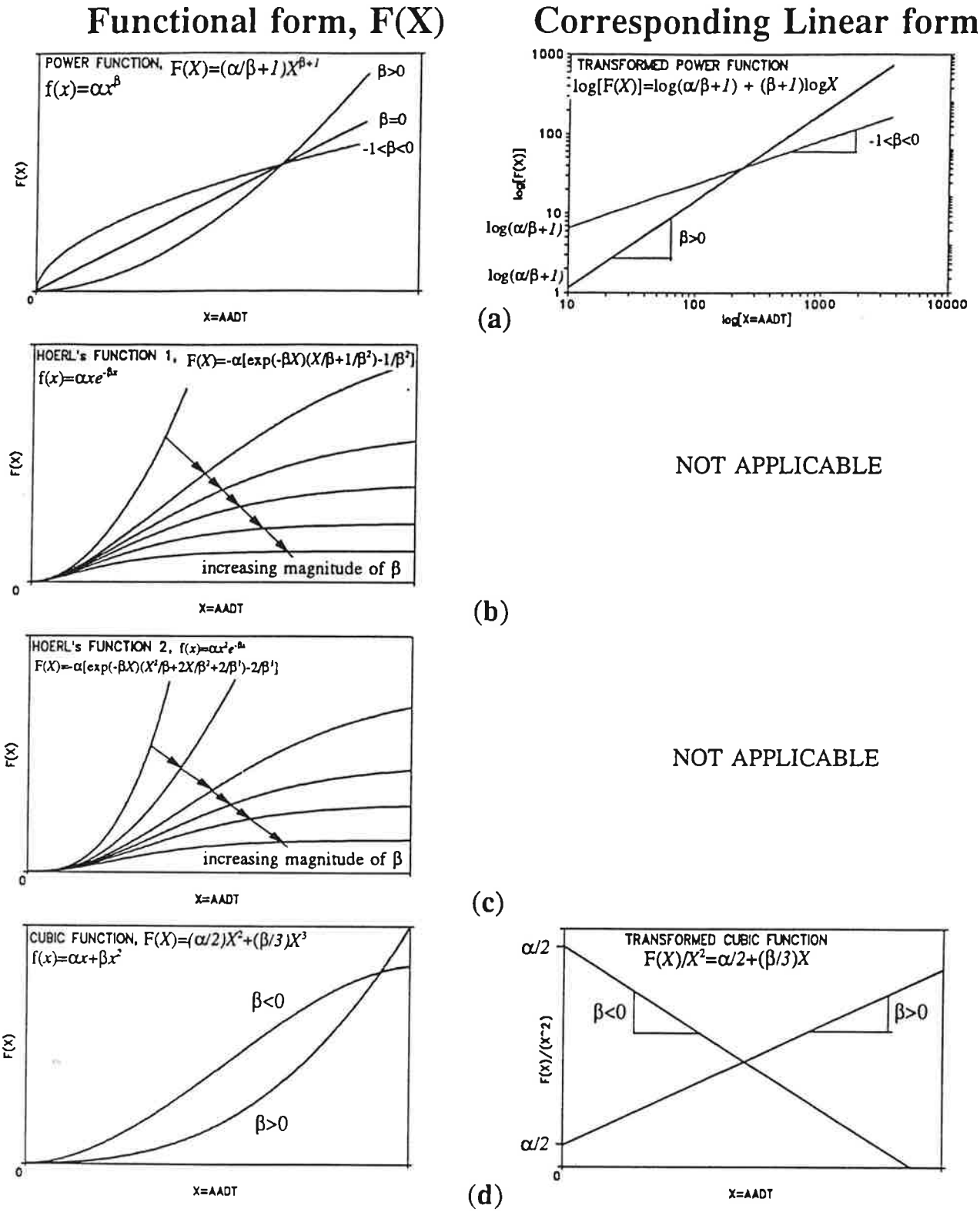


Figure 3: Graphical illustrations of candidate F(*X*)s.

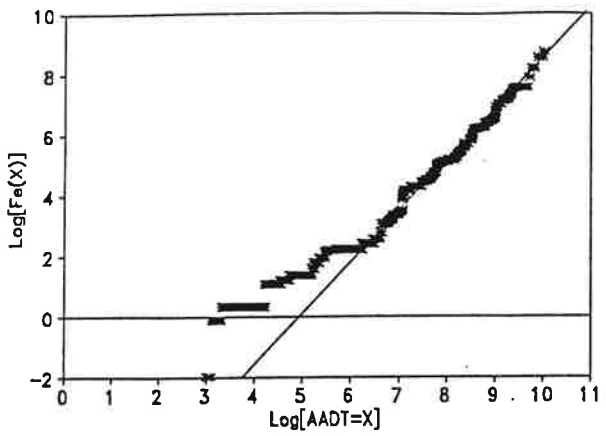


Figure 4: Does the transformed F_1 fit as a straight line?

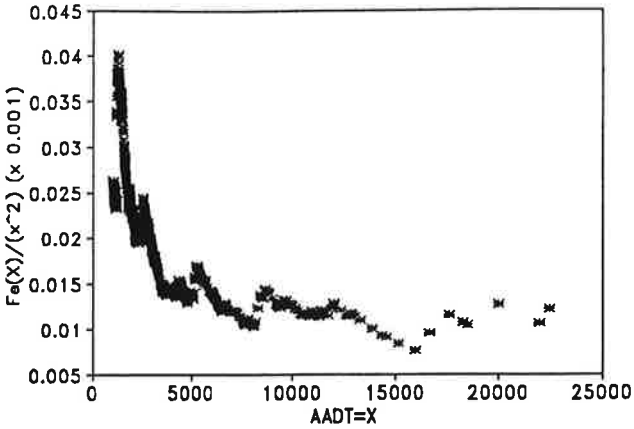


Figure 5: Does the transformed F_2 function fit the data?

and $\beta+1$ as slope. Similarly, if F_2 is suitable, then plotting $F_E(X)/X^2$ against X should yield a straight line with the intercept $\alpha/2$ and slope $\beta/3$. The two plots are shown as Figures 4 and 5.

It appears that the power function F_1 will fit the data well for AADT≥700 [log(700)=6.5]. The cubic function F_2 does not seem to fit the data well for AADT<5000 or so. Thus, while neither one of the two identified candidates promises to be a good fit over the entire range of the variable, the power function seems to be the more suitable candidate.

There exist, of course, many other candidate functional forms. If their $F(X)$ can not be easily transformed into a linear form there is probably no better choice than to estimate their regression constants by the usual means and then to examine their residuals by the method described in Section 3.

3. Judging Model Adequacy by CUmulative REsiduals - the CURE method.

Examination of the empirical integral function in Figure 2 suggested that an equation of the form $\alpha \times AADT^{\beta}$ be used. Using the Generalized Linear Interactive Modeling (GLIM) software and the negative binomial error structure we estimated α to be 0.001266 and β as 0.5438. The customary plot of residuals is shown in Figure 6. Every point in it is an accident count of 0, 1 or 2 from which the value of the model equation at that AADT is subtracted. Figure 6 is of little use in assessing whether the chosen model form has flaws just as Figure 1 was useless in

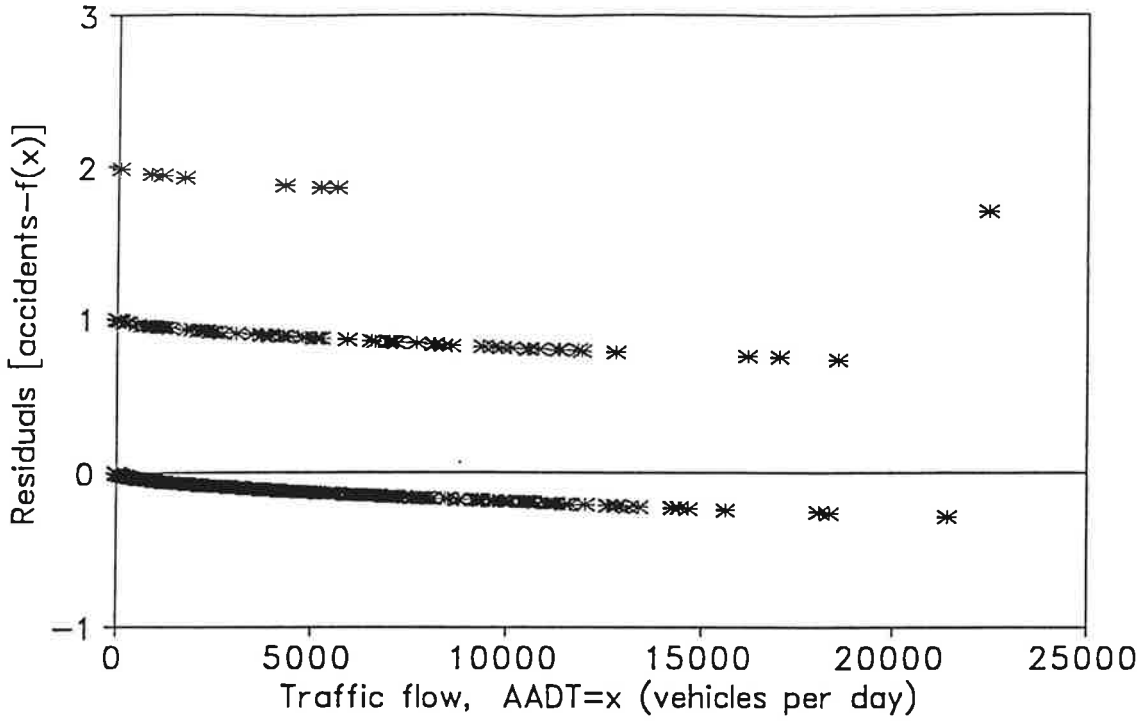


Figure 6: Plot of residuals for data in Figure 1.

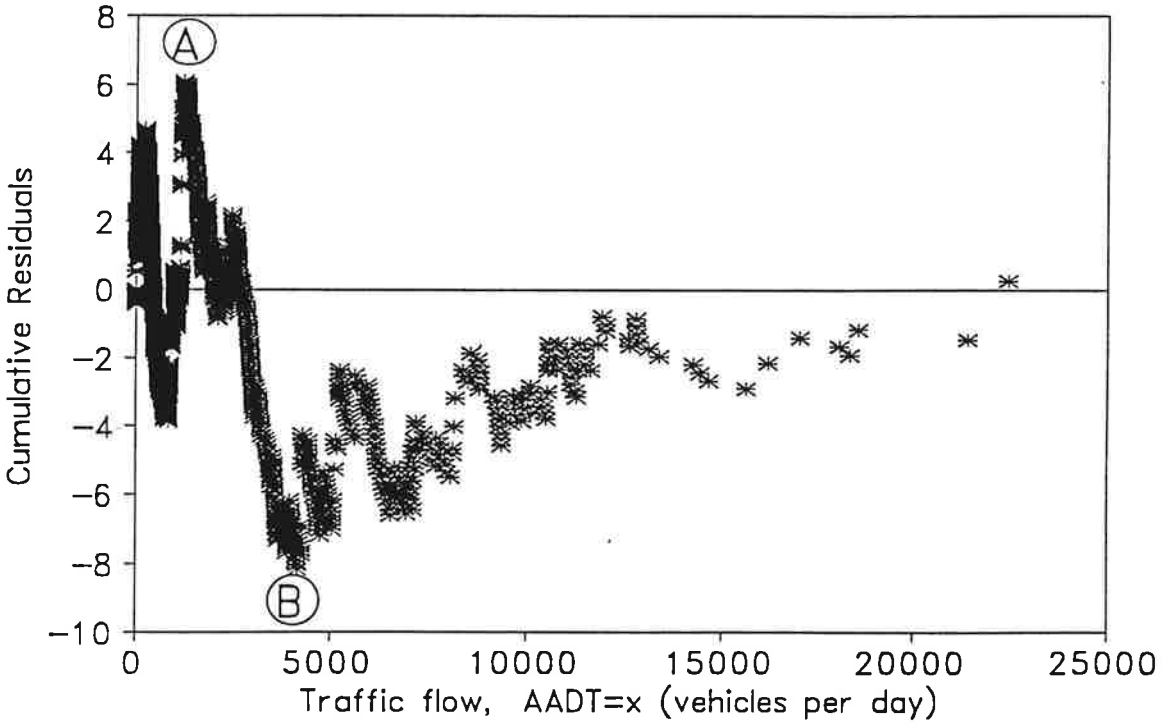


Figure 7: Cumulative residuals versus AADT.

determining what the functional form should be used. A much more informative picture emerges when the consecutive residuals are accumulated as in Figure 7. If a model equation fits the data along the entire range of values assumed by a variable, one expects the cumulative graph to be a random walk oscillating around 0. Furthermore, depending somewhat on the principle used for parameter estimation, one expects the random walk to end close to 0. The question arises, whether a cumulative graph of the kind shown in Figure 7 is a sign that the model is flawed for some ranges of the variable, or whether it is compatible with a random walk of a model fitting over the entire range of the variable, such that the mean of all residuals is 0.

The graph in Figure 7 indeed oscillates around 0. When along a stretch of the horizontal axis the cumulative residuals consistently drift upwards, along that stretch there are more accidents then what the model predicts. Conversely, when the cumulative residuals consistently drift down, the model overestimates the accident count. Thus, for example, from point A at which the residuals accumulate to about +6 (after 1123 road sections at AADT≈1300) to point B at which the residuals accumulate to about -8 (at road section 1535 and AADT≈4200), the model seems to overestimate the accident counts. Similarly from point B on, the estimates produced by this model form seem to be consistently too small. Since a grand total of 108 accidents occurred on these road sections in the three years, it is difficult to judge whether such peak accumulations (+6, -8) are a sign of a poor fit. Some formal tool is needed to distinguish between what may be expected if the model fits perfectly and what is a sign of a systematic bias.

Let the residuals be arranged in increasing order of an explanatory variable of interest. They are now numbered consecutively, such that N is the total number of data points (residuals), n is an integer between 1 and N, and $S(n)$ the sum of the residuals from 1 to n. If the mean of all residuals is 0, then $E\{S(n)\}=0$. On the assumption that $E\{S(n)\}=0$ for all n, the variance of $S(n)$, to be denoted as $\sigma^2(n)$, can be estimated from the graph of cumulative squared residuals such as that in Figure 8 which pertains to the Maine data used in all earlier illustrations. Thus, for instance, with statistically independent residuals, at point A of Figure 7, $\sigma^2(1123)$ is estimated as 39.4, and at point B of Figure 7 $\sigma^2(1535)$ is estimated as 63.5. In total, $\sigma^2(N=1796)$ is estimated as 111.4.

Even if the individual residuals do not have the same variance, one can invoke some loose version of the central limit theorem to argue that the sum $S(n)$ is normally distributed with mean=0 and variance read of a cumulative graph such as that in Figure 8. Similarly, the sum of the residuals for the remainder of the random walk has a mean 0 and a variance estimated

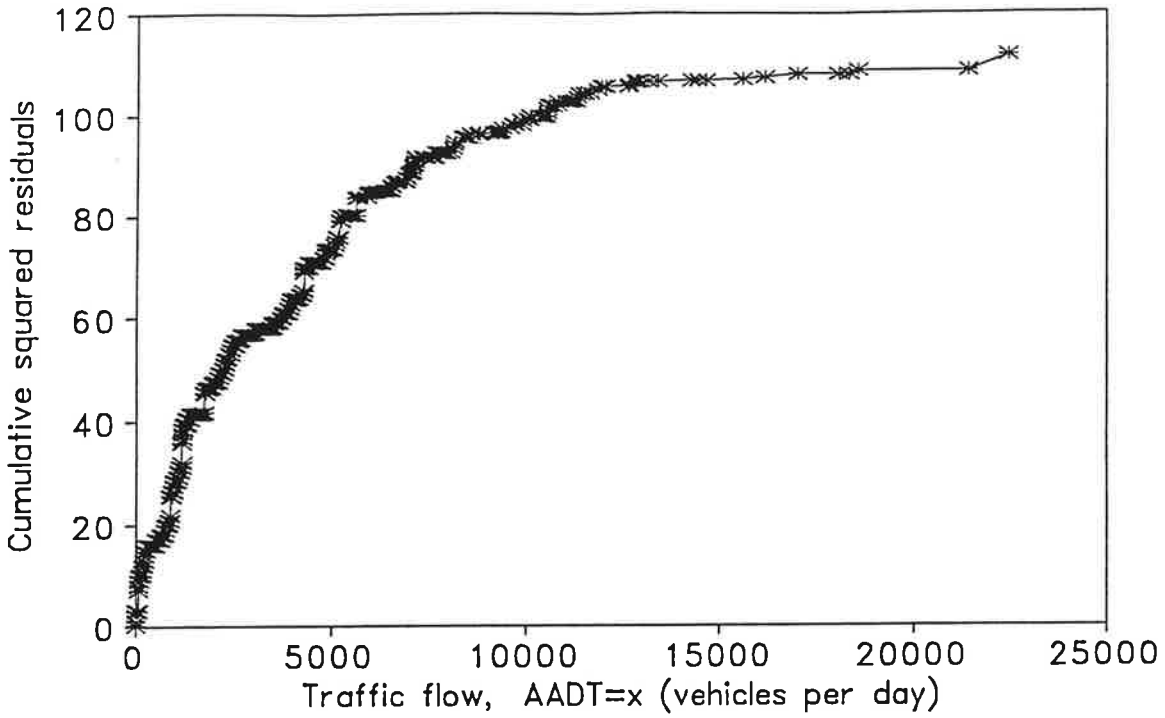


Figure 8: Cumulative squared residuals versus AADT.

from the rest of the graph. On this basis, the probability density function for the realization that the random walk reaches S=s at n and returns to 0 at N is the product of two normal probability densities. One with mean 0 and variance $\sigma^2(n)$ and the other with mean 0 and variance $\sigma^2(N)$-$\sigma^2(n)$. The product can be written as:

$$\frac{1}{\sqrt{2\pi\,\sigma(n)}}e^{-\frac{s^2}{2\sigma^2(n)}} \times \frac{1}{\sqrt{2\pi\sqrt{\sigma^2(N)-\sigma^2(n)}}}e^{-\frac{s^2}{2[\sigma^2(N)-\sigma^2(n)]}} \quad \ldots\ldots\ldots \quad (1)$$

The part of equation (1) with the exponents can be rewritten as

$$e^{-\frac{s^2}{2\sigma^2(n)}} \times e^{-\frac{s^2}{2[\sigma^2(N)-\sigma^2(n)]}} = e^{-\frac{s^2}{2}\frac{\sigma^2(N)}{\sigma^2(n)[\sigma^2(N)-\sigma^2(n)]}} = e^{-\frac{s^2}{2\sigma*^2}} \quad \ldots\ldots\ldots \quad (2)$$

with,

$$\sigma^{*2} = \frac{\sigma^2(n)[\sigma^2(N) - \sigma^2(n)]}{\sigma^2(N)} = \sigma^2(n)\left(1 - \frac{\sigma^2(n)}{\sigma^2(N)}\right) \quad \ldots\ldots\ldots \quad (3)$$

The remaining part of equation (1) can be rewritten as

$$\frac{1}{\sqrt{2\pi\sigma(n)}} \frac{1}{\sqrt{2\pi\sqrt{\sigma^2(N) - \sigma^2(n)}}} = \frac{1}{\sqrt{2\pi\sigma(N)}} \frac{1}{\sqrt{2\pi\sigma^*}} = constant \frac{1}{\sqrt{2\pi\sigma^*}} . \quad (4)$$

Thus, the product in equation (1) represents a normal probability density with mean 0 and standard deviation σ^* that is multiplied by the constant $1/\sqrt{[2\pi\sigma(N)]}$. Therefore, the probability density for a random walk that ends at 0 to pass through $S(n)=s$ is normal with a mean of 0 and variance $\sigma^{*2}=\sigma^2(n)[1-\sigma^2(n)/\sigma^2(N)]$.

In the numerical example, $\sigma^2(1123)$ was estimated to be 39.4 and $\sigma^2(1796)$ was estimated as 111.5. Thus $\sigma^{*2}=39.4(1-39.4/111.4)=25.5$ and $\sigma^*=5.1$. Recall that the observed S(1123) was about 6. That is slightly more than one standard deviations from the mean and entirely compatible with the hypothesis that the model residuals are 0 everywhere. Similarly at $n=1535$ where S(1535) is about -8, $\sigma^{*2}=63.5(1-63.5/111.4)=27.3$ and $\sigma^*=5.2$. Since $-8/5.2<2$ the random walk at its extremes is contained within two standard deviations of what would be expected if the fit was perfect. Since σ^* varies with n and is 0 near the edges, it is perhaps best to examine the entire plot of $2\sigma^*$ against the background of the cumulative residuals is shown in Figure 9.

Recall that the plot of cumulative squared residuals (such as that in Figure 8) estimates $\sigma^2(n)$ on the assumption that $E\{S(n)\}=0$. This will almost never be exactly true. If so, the plot of cumulative squared residuals will contain some bias and $\sigma^2(n)$ is in truth less than the value of the cumulative squared residual at n. As a result the $\pm 2\sigma^*(n)$ band such as that shown in Figure 9 is somewhat wider than it should be.

In conclusion, the functional form chosen in the illustration seems to produce estimates of κ that are slightly too high for $1300<AADT<4200$ and slightly too small for $AADT>4200$. It is

possible that a different model functional form, one that shapes the curve in accord with these observations, can be found. Thus, for example, the model $0.003466 \times AADT^{0.3721} \times e^{0.000072 \times AADT}$

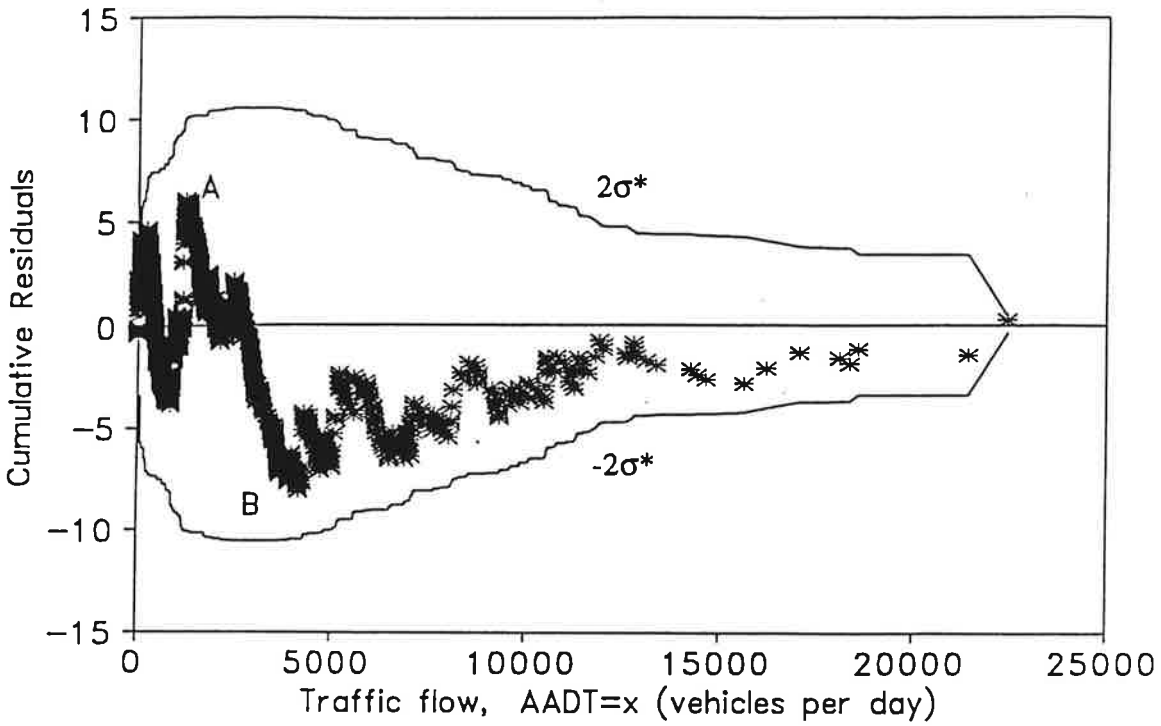


Figure 9: Cumulative residuals and the ±2σ* band

will produce a better cumulative residual plot. However, inasmuch as the cumulative residuals in Figure 9 are not inconsistent with the hypothesis that all expected residuals are 0, we adopt tentatively, for the explanatory variable "AADT", the simpler form, $0.001266 \times AADT^{0.5438}$.

The purpose of this section was to show that when data are noisy and the plot of residuals against some variable is uninformative (as is, e.g., Figure 6), the plot of cumulative residuals may still be interpretable and useful. The very same CURE technique is useful also when one wishes to ascertain whether a new explanatory variable should be introduced into the model equation. Produce the graph of cumulative residuals against the candidate explanatory variable. Using the cumulative squared residuals, when arranged in the order of the new explanatory variable, estimate the $\sigma^*(n)$. If the graph of cumulative residuals oscillates around 0, ends near 0, and is confined within, say, $\pm 2\sigma^*(n)$, the new explanatory variable will not be useful.

In the numerical illustrations so far, we used only traffic volume (AADT) as an explanatory variable. Section length was kept constant at 0.05 miles. In the next section we will introduce section length as the additional explanatory variable. It is not really necessary to use the CURE technique to determine whether section length is needed. In fact, one may speculate that κ should be proportional to road section length. However, since some researchers found to the contrary, an empirical examination is in order. More generally, the discussion so far has been confined to the case when κ is a function of one variable only. In the next section we illustrate the application of the ID approach to the case when the model equation contains several explanatory variables.

4. Generalization to more than one explanatory variable.

Consider a model equation of the form $\kappa=f_1(x_1)f_2(x_2)$ and assume that the functional form and regression constants of $f_1(x_1)$ are known. We wish to ascertain the functional form of $f_2(x_2)$. In Section 2, where κ was considered to be a function of only one variable, we made use of the Empirical Integral Function of κ. The idea here is to use the Empirical Integral Function of the ratio, $\kappa/f_1(x_1)$, considering provisionally $f_1(x_1)$ as known.

To illustrate, let the road section length d be the argument of f_2. On logical grounds we expect $f_2(d)$ to be as straight line through the origin. The reason is that if we divide a homogeneous road section into two segments, we expect the number of accidents on the original section to be the sum of the number expected on the two segments.

As earlier for AADT, we need to determine the bin widths and bin heights for the data. Our data now is about 40,753 two-lane, rural road sections in Maine that vary in length from 0.01 miles to 4.89 miles. (In the preceding sections we used a subset of 1796 road sections that are 0.05 miles long.) Of the 489 possible values of d, 341 are actually represented in the data. Bin width will be determined, as before, by the difference between the nearest higher and nearest lower section length divided by two. As bin height we will use the ratio: (count of accidents for all the road sections in bin)/(number of accidents predicted by $\alpha \times AADT^{\beta}$ for all the road sections in the bin). These are the ordinates in Figure 10.

In this case it may seem that further inquiry is not needed. The reliably determined points (say, those for $d<1.3$ miles where each bin contains more than 100 accidents) clearly chart a straight

line through the origin. Thus, we seem to find what should hold true, namely, that $f_2(d)$ is a straight line through the origin. It is tempting to conclude that the same relationship holds also

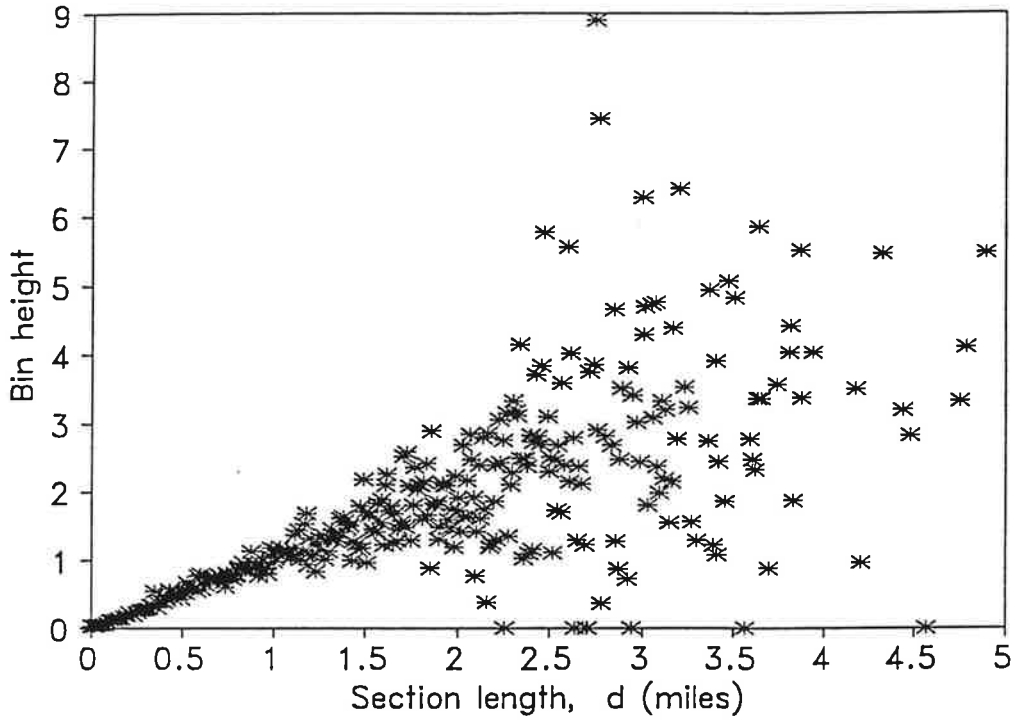


Figure 10: Bin height versus section length

beyond, say, d>2 miles. However, since here the points could admit many functional forms, the Empirical Integral Function could again be useful. It is shown in Figure 11.

As earlier, the Empirical Integral Function creates order in the cloud of points in the right portion of Figure 10. If κ is proportional to d, then the curve in Figure 11, representing the integral, should be proportional to d^2 and pass through the origin. Whether this is so can be judged in the log-log transform of Figure 12, where it should therefore plot as a straight line of slope 2. Indeed, to the right of $\log(d)\approx$-2.3 or, when $d\geq$0.1 miles, the $\log[F_E(d)]$ appears to be a straight line with the correct slope of about 2. How good the fit is, can be judged by the straight line of slope 2 shown near the data points of Figure 12. However, when d<0.1 miles, $\log[F_E(d)]$ may not be a straight line and if it is, the slope is not 2. This implies that for 0<d<0.1 miles, the expected number of accidents is not directly proportional to d.

This violates the basic logical requirement enunciated earlier. The reasons for this fault in the

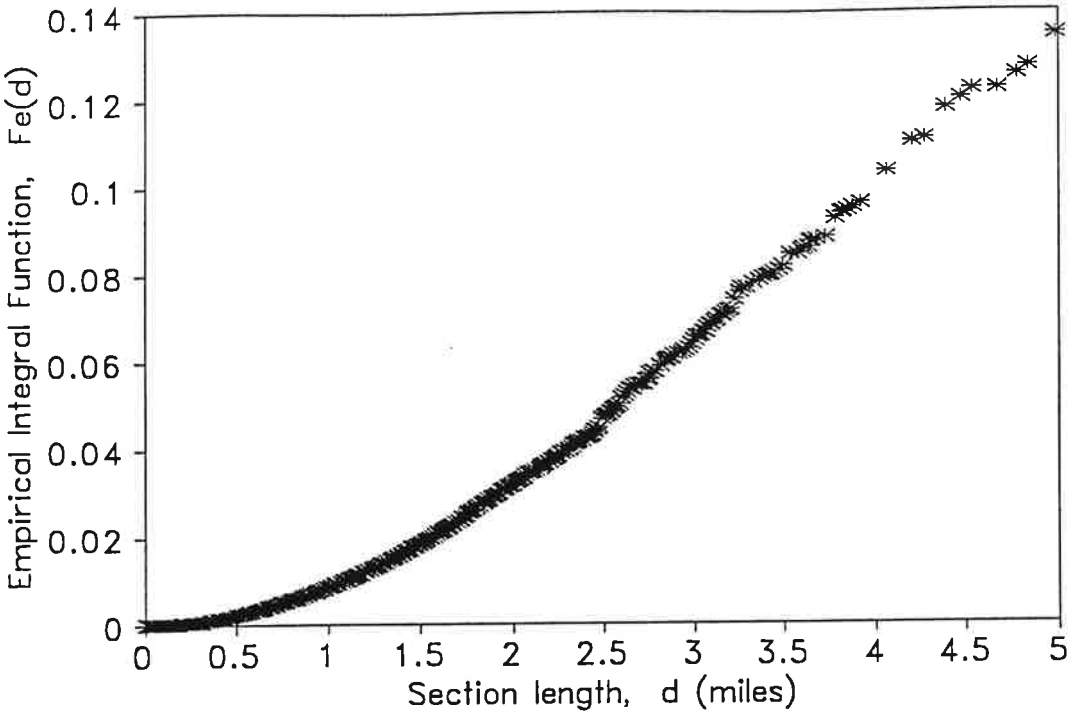


Figure 11: Empirical Integral Function for section length

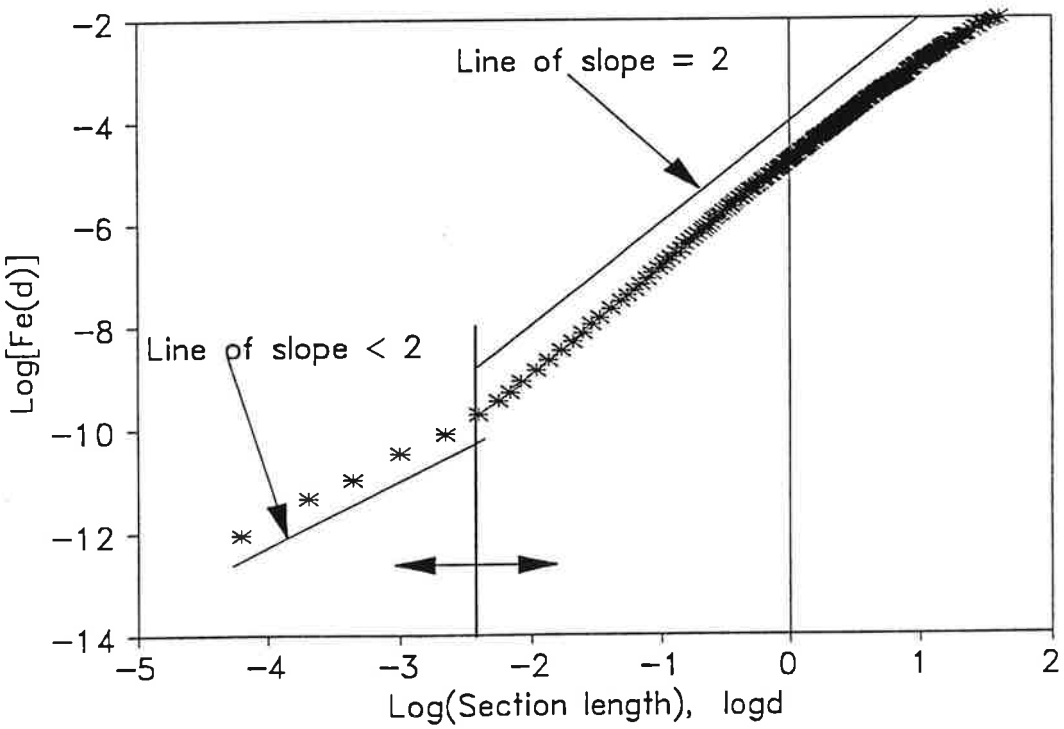


Figure 12: Transformed Empirical Integral Function for section length.

data can be several. First, section length in the data base is dictated by the requirement that traffic and road characteristics remain the same along the entire section. Thus, intersection density and road characteristics may be associated with both section length and accident occurrence. Second, present practice by police is to locate accidents within the nearest tenth of a mile. Since the data base is built on accident reports by police, it is not clear how well a finer location determination could have been made in the data base. The upshot of this finding is that road sections shorter than 0.1 miles should either be reassembled into longer sections or removed from the data base used for modeling.

The main purpose of this section was to show how the ID method can be used to build model equations with several explanatory variables. The approach applies only to model equations which are the product of several functions, each with one explanatory variable. The main idea is to examine one function at a time and to move the functions already examined into the denominator of κ.

5. Summary and Discussion.

Multivariate statistical modeling can be thought to consist of deciding what explanatory variables to use in the model equation, deciding what the functional form of the model equation should be, and of estimating the unknown regression constants. The tools for the estimation of regression constants are well developed. However, they are of little use if an inappropriate functional form or the wrong explanatory variables were selected. If the results are to be used to predict what will be the change in the dependent variable as a result of a change in an explanatory variable, it is crucial that the right functional form and explanatory variables be used in the model equation. The aim of this paper is to add to the arsenal of tools for choosing an appropriate functional form and for deciding whether a candidate explanatory variable needs to be added to the model equation.

Two such tools are discussed. The first helps to choose the functional form of the model equation and is named the Integrate-Differentiate (the ID) method. Its application is of advantage when the scatterplot of dependent versus explanatory variable is a formless cloud to which almost all functional forms could apply. The central idea of the ID method is that the formless cloud turns into a fairly definite pattern when the data is represented as an Empirical Integral Function.

The transformation of a scatterplot into an Empirical Integral Function requires no assumptions and involves no loss of information.

The use and usefulness of the ID method has been demonstrated on data about single-vehicle non-intersection accidents on rural two-lane roads in Maine. In one instance of application, it proved possible to first identify the power function of traffic flow and the parabola as candidate functional forms, and then to determine that the power function is the more suitable candidate of the two. In the next instance of application, the ID method was used to determine the functional form in which the explanatory variable 'section length' should enter the model equation. Not only could we confirm that what is logically sound is strongly supported by data, we could also demonstrate that for road sections shorter than 0.1 miles the logical relationship is violated and concluded that such sections must not be used in modeling.

The ID method, as presented, applies only to functional forms that are products of functions of one variable (i.e., $f_1(x_1) \times f_2(x_2) \times \ldots$). Whether it can be extended to more general functional forms, considering two or more explanatory variables at once, requires further inquiry. As explained, the ID method is not an automatic procedure. It requires that the analyst examine each explanatory variable separately, with the model equation evolving one explanatory variable at a time, and with the need to occasionally revisit the functional form of variables already examined.

The second tool discussed in this paper, the CURE method, is tied to the examination of residuals after regression parameters were estimated. Its purpose is twofold. First, it can be used to examine whether the chosen functional form indeed fits the explanatory variable along the entire range of its values represented in the data. If not, it informs the search for a better functional form. Second, it can also be used to ascertain whether a candidate explanatory variable, one not yet used, should be introduced into the model equation. The central idea is that even when the usual plot of residuals does not show any systematic drift, by examining the cumulative residuals, potentially important patterns may emerge.

The plot of cumulative residuals should oscillate around 0, end close to 0, and not exceed the $\pm 2\sigma^*$ bounds determined by equation 2. Even if these bounds are not infringed upon but there are long stretches where the model consistently drifts up or down, consideration can be given to improving the model form. When the residual is defined as the difference between the accident count and the model prediction, an upward drift is a sign that the model consistently predicts

fewer accidents than were counted. Of course, if the endpoint is not near 0, there is something wrong with the estimated regression constants.

The two tools discussed in this paper require a cyclical process of multivariate statistical modeling, one in which the functional form evolves gradually, its regression parameters are periodically re-estimated and the cumulative residuals used to both revise the functional form to try out new explanatory variables. It is our prejudice to think that the need for a cyclical process is a useful feature of the suggested tools.

Pedestrian Risk decrease with Pedestrian Flow and Increase with Vehicle Flow - A Case Study

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Abstract

We used a unique database providing pedestrian accidents and estimates of pedestrian and vehicle flows for the years 1983 - 1986 for approximately 300 signalized intersections in Hamilton, Ontario, Canada. Pedestrian safety at semi-protected schemes, where left-turning vehicles face no opposing traffic but have potential conflicts with pedestrians, were compared with pedestrian safety at normal non-channelized signalized approaches, where right-turning vehicles have potential conflicts with pedestrians.

Four different ways of estimating hourly flows for left- and right-turning vehicles were explored. Parameter estimates were affected by the time period used for flow estimation. However, parameter estimates seem to be much more affected by the traffic pattern (left or right-turning traffic) even though approaches were selected so that the situation for left and right-turning turning traffic should be similar (no opposing traffic, no advanced green or other separate phases and no channalization). Left-turning vehicles causes higher risks for pedestrians than right-turning vehicles, probably due to higher speeds caused by larger radius for left-turning vehicles. At low vehicular flows right turns and semi-protected turns tend to be equal safe for pedestrians.

If risks for pedestrians are calculated as expected number of reported pedestrian accidents per pedestrian, risks decrease with increasing pedestrian flows and increase with increased vehicle flow.

1. BACKGROUND AND PURPOSE

My work focused on safety for pedestrians with conflicting left and right-turning turning vehicles and how the models are influenced by the choice of different time period for estimating pedestrians and vehicle flows. The conceptual framework in this context and the method used is explained in detail elsewhere (Leden, 1993). Data was also used to analyze how to typical schemes for accommodating left turning vehicles influence the safety for pedestrians (Quaye *et al*, 1993).

2. THE DATA

The data gathering part in my project was started by Almuina (1989). His work focused on pedestrian accidents and left-turning vehicles at signalized intersections. As a part of his work he prepared an Accident Database and an Intersection Geometry Database for the approximately 300 signalized intersections in the Regional Municipality of Hamilton-Wentworth (Region) located within south central Ontario. The majority of the intersections are located in the City of Hamilton in a typical American grid network with many one way streets.

To enhance the chances of success to find a "pure" relation between pedestrian accidents and pedestrian and vehicle flows I selected for analysis a set of signalized approaches which are similar in most respects except traffic flows and accident history. For accidents involving right-turning vehicles I gathered data for approaches which were not channelized, *i.e.* there was no extra island to exclude right-turning turning traffic from signal control and let them yield towards pedestrians. For accidents involving *left-turning* vehicles I used the following criteria to select approaches:

- no opposing traffic i.e. semi-protected scheme and
- no advanced green for left-turning traffic or other separate phase for left-turning traffic.

No opposing traffic in the approach could be due to the missing leg in a three-way intersection or due to one-way traffic in the opposite approach in the direction away from the approach. To decide which approaches fulfilled the criteria I used the information provided in the Intersection Geometry Database and in micro-fiches of the lay-out of the intersections. I got information about advanced green or other separate phase for left-turning traffic by interviewing the engineer in charge in the city of Hamilton (Mr. Hart Solomon).

The city of Hamilton provided us with stream counts of vehicles and pedestrian for fifteen minutes periods for 1983 to 1986. Typically there was one or two counts per year at each intersection. Counts were conducted from 7 to 10 a.m. and from 14 to 18 p.m. Monday to Friday and reported in fifteen minutes periods. From these counts hourly flows were estimated for *each* fifteen minutes period for *all* Mondays to Fridays during the study period. These estimations were used as basis for estimating average hourly flows in four different ways, see chapter 4. As available accident data was for 1977 to 1986 estimates of flows had to be extrapolated for the years 1977 to 1982 to correspond with the accident data. However these extrapolated estimates did not seem to be reliable, so this paper is restricted to describe the analysis of data from 1983 to 1986. The method to estimate flows is described by Quaye, Leden & Hauer (1993).

To correspond to the available traffic count information, I used only those accidents that occurred between 7 to 10 a.m. and between 14 to 18 p.m. Monday to Friday and which involved left-turning or right-turning vehicles and a pedestrian. 63 accidents from 1977 to 1982 and 66 accidents from 1983 to 1986 remained for the analysis. As already mentioned the analysis were restricted to describe the analysis of data from the years *1983 to 1986*. So I have a total of 66 accidents, 27 of them between left-turning vehicles and pedestrians and 39 between right-turning turning vehicles and pedestrians.

3 METHOD

The cause-and-effect relationship between accidents and traffic flows is of course crucial. For example does the straight-through flow not affect the safety for pedestrians at signalized intersections much and only those walking against red light. So the accidents were related to the flows to which the colliding vehicle and pedestrian belong, i.e. to specific accident patterns.

On the basis of an exploratory analysis, one can suggest functional forms for expressions that fit what has been observed. As I had only a small number of accidents my conclusion could not be very firm. Experience gained from previous work (Hauer et al, 1988) suggested that it could be reasonable to use the following form of the model:

$$x_i = b_0 F_1^{b_1} F_2^{b_2} + e_i = \hat{E}\{m\}_i + e_i \qquad (1)$$

where for each case *i*
x_i is the observed number of accidents per unit of time
$\hat{E}\{m\}$ is the estimated number of accidents per unit of time,
F_1 is the vehicle flow per hour (right-turning or left-turning)
F_2 is the pedestrian flow per hour and
e_i is the "error" variable, the residual.

My exploratory analysis supported this form.

The usual approach to the analysis is by multiple regression. To estimate parameters we have to transform the function in equation 1 by taking logarithmic values. The model, expressed in a traditional form can then be written:

$$y_i = \ln x_i = b_0 + b_1 \ln F_1 + b_2 \ln F_2 + e_i = m_i + e_i \qquad (2)$$

I estimated coefficients using the Generalized Linear Interactive Modeling (GLIM) software package (Aitkin *et al*, 1986). In this package it is possible to choose an appropriate error distribution. To be able to do the right choice it is necessary to understand the conceptual framework, which will be discussed below.

I have denoted m_i the safety of a specific intersection. Imagine a population of intersections that all have the *same traffic flows*. In this imaginary population, the m_i's would still vary from intersection to intersection because, although flows are identical, they involve different drivers in different cities, and so forth. Thus, one can speak of the expected value or mean of the *m*'s ($E\{m\}$) in this imaginary population of intersections with *identical* traffic flows. This mean of *m*'s is what describes the safety of a representative or an average intersection for this imaginary population of intersection with a specific traffic flow. Similarly, one can speak of the variance of the *m*'s.

When fitting a model to accident data, I am trying to estimate E{m} as a function of traffic flow (in this case). That is, I am trying to determine what the m is of some average or representative intersection and how it varies with traffic flow. However, the data used for estimation are not for average intersections. Each accident count I use is for one specific intersection from the imaginary population of intersections with the same flows. It follows that if E{m} is what I wish to estimate, the accident count must be considered as a Poisson random variable that comes from a site with E{m_i} as its expected value and that this m, in turn, is one of a distribution of m's characterized by E{m} and Var{m}.

Thus, the distribution of accident counts around the E{m} is one family of "compound Poisson distributions." In the special case in which the distribution of m's in these imaginary populations can be described by a gamma probability density function, the distribution of accident counts around the E{m} must be taken as negative binomial, or with other words the error distribution e_i is *negative binomial*.

The variance of accident counts s^2 is given by Var{m} + E{m} or

$$\hat{Var}\{m\} = s^2 - \bar{x} \qquad (3)$$

Note that the relationships are not affected of the transformation into a logarithmic scale according to equation 2. In principle these relationships can be used to estimate Var{m} for different subsets of the data with almost the same $\hat{E}\{m\}$. I have not enough data for this. I have to use results from work already done. It is described by Hauer et al (1991). As $\hat{Var}\{y_i\} = \Sigma e^2/n$ clues to $\hat{Var}\{m\}$ are contained in the residuals e_i. Hauer and Persaud (1987) found that there often is a relationship between E{m} and Var {m} and that it can usually be adequately represented by:

$$Var\{m\} = (E\{m\})^2/k. \qquad (4)$$

where k is the first parameter for the negative binomial distribution.

This means that the same relationship is valid for subsets of data as for data for the whole Gamma distribution. From equation 4 we get for the whole distribution:

$$Var\{m\} = k/\lambda^2 = k^2/(\lambda^2 k) = (E\{m\})^2/k.$$

Hauer *et al* (1991) confirmed the validity of this empirical finding for many groups of their data base by using equation 3.

There are two different methods, which can be used to estimate k, the method of moments and the maximum likelihood method. I chose to use the latter one. However some examples calculated by both methods indicated that the two methods gave similar results.

Maycock and Maher (1988) suggests the method of moments to estimate k. As in equation 2, e_i is the residual (y_i - m_i), then

$$E\{e^2\} = m_i + m_i^2/k$$

and an estimate of k is given by:

$$k = \sum \hat{m}_i^2 \; / \; \sum (e^2 - \hat{m}_i) \; . \qquad (5)$$

Hauer *et al* (1991) describe the maximum likelihood method of estimating *k*. The iterative process of estimating $\hat{Var}\{m\}$ begins by estimating provisional model parameters on the assumption that $\hat{Var}\{m\} = 0$ or using some other starting guess. Once I have provisional parameter estimates I can find an estimate of *k* that maximizes the likelihood (L) of the data as follows. As showed above the accident counts can be assumed to be negative binomial distributed; the parameter a for the negative binomial model can be expressed as a function of k and $E\{m_i\}$ by using that $E\{m_i\}=b/a$ and $Var\{m_i\}=b/a^2= (E\{m_i\})^2/k$. So the probability of an accident count x_i for case number i can be written as:.

$$p(x_i) = [a/(a+1)]^k \; [k(k+1) \ldots (k+x_i-1)/x_i! \; [(a+1)^{Xi}] =$$

$$[k/E\{m_i\}]^k \; [k(k+1) \ldots (k+x_i-1)]/[x_i! \; (k/E\{m_i\}+1)^{x_i+k}].$$

The likelihood function *L* describes the probability of having the actual outcome of accident counts $x_1, \ldots, x_i, \ldots x_n$. If events are independent this probability can be calculated as $\Pi\, p(xi)$. To facilitate calculations ln L is calculated instead of L, so,

$$\ln L = \ln \Pi\, p(x_i) = k \; [\Sigma \ln(k/E\{m_i\})] + \Sigma[\ln(k) + \ln(k+1) + \ldots + \ln(k+x_i-1)] - \Sigma(x_i+k) \ln(1+k/E\{m_i\}) + \text{constant}^1. \qquad (6)$$

Since we have estimates for $E\{m_i\}$, it is easy to find that value of k which maximizes ln*L* (and *L*) by calculating ln*L* for different values of k. This k is then used to calculate $\hat{Var}\{m\}$ by equation 4. The provisional error structure is revised, and model parameters are estimated anew. The process converges in two or three iterations.

As I had a very small database the estimates of k in my case were very uncertain and in some cases it was not even possible to calculate the estimate of k which maximizes the likelihood. However, the estimates of the model parameters were not very sensible for changes in k.

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[1] not dependent on k

4 RESULTS

My work focused on how the models describing pedestrian safety are influenced by the choice of a different time period for estimating the hourly flows. I explored four different ways of estimating hourly flows:

1 average daily flow for each year, *daily model*

2 average hourly flows during a.m. and p.m. periods for each year, *i.e.* 7 to 10 a.m. and 14 to 18 p.m. for 1983, 1984 etc., *a.m./p.m. model*

3 average hourly flows for each hour and year, *i.e.* 7 to 8:00, 1983, 8:00 to 9:00, 1983 etc. *hourly model* and

4 average hourly flows for each fifteen minutes period and year, *i.e.* 7 - 7:15, 1983, 7:15 - 7:30, 1983 etc. *15 minute model.*

In all models estimated, the traffic flows are expressed in vehicles or pedestrians per hour. The dependent variable in each model was based on the number of police reported accidents occurring in the corresponding time periods (*e.g.* for the daily model the number of police reported accidents per day during study hours 7 to 10 a.m. and 14 to 18 p.m. was used etc. The parameter estimates obtained, after fitting the 8 models using the Generalized Linear Interactive Modeling (GLIM) software package are given in equation 7 and Tables 1 and 2.

$$\hat{E}\{m\} = b_0 F_1^{b_1} F_2^{b_2} \qquad (7)$$

m is the expected number of accidents per unit of time of a certain intersection with an hourly right or left-turning vehicular flow F_1 and hourly pedestrian flow F_2,

$\hat{E}\{m\}$ is the estimated number of accidents per unit of time of a certain intersection

b_0, b_1 and b_b are parameters to be estimated.

Table 1. Parameter estimates for *left-turning* vehicles.

Flow period	$\hat{b}_0$	$\hat{b}_1$	$\hat{b}_2$	$\hat{k}$
1. day	$2.62\ 10^{-7}$	1,19	0,331	2,2
2. a.m./p.m.	$4.85\ 10^{-8}$	1,37	0,346	*
3. hour	$1.82\ 10^{-8}$	1,32	0,338	0,4
4. 15 minutes	$3.61\ 10^{-9}$	1,35	0,368	*

* not enough data for estimating k

Table 2. Parameter estimates for *right-turning* turning vehicles.

Flow period	$\hat{b}_0$	$\hat{b}_1$	$\hat{b}_2$	$\hat{k}$
1. day	$4.19\ 10^{-7}$	0,864	0,475	*
3. a.m./p.m.	$1.19\ 10^{-7}$	0,919	0,570	*
4. hour	$4.08\ 10^{-8}$	0,913	0,514	*
5. 15 min.	$2.43\ 10^{-8}$	0,864	0,321	*

* not enough data for estimating k

It should be noted that the estimate from the daily model pertains to information aggregated over *2* a.m. or p.m. periods, *7* hours of the day (specifically: 7 to 10 a.m. and 2 to 6 p.m.), or *28* fifteen minutes periods. Ideally, one would expect that multiplying the 15 minute estimate of E{m} by 28, the hourly estimate by 7 or the a.m./p.m. estimate by 2 should yield the daily estimate. Figures 3 and 4 illustrate this. In these figures, the curves labeled 1 gives the daily estimates of E{m}, based on the daily model, for various values of left- or right-turning vehicular flow F_1, when pedestrian flow F_2 is 50 pedestrians per hour in Figure 3 and 500 pedestrians per hour in Figure 4. Curves 2, 3 and 4 are daily estimates obtained from the a.m./p.m., hourly and 15-minute models respectively, for the same traffic flow combinations.

It is evident from Figure 1 that estimates from the 4 different models gives similar estimates. Left-turning vehicles causes higher risks for pedestrians than right-turning vehicles, probably due to higher speeds and larger radius for left-turning vehicles. If risks for pedestrians are calculated as expected number of reported pedestrian accidents per pedestrian, *i.e.* equation 9 is divided by 7 F_2 (daily pedestrian flow), risks are decreasing with increasing pedestrian flow. Figure 2 shows estimates for F_1 = 50 vehicles per hour and Figure3 for 500 vehicles per hour. For small vehicle flows risk differences vanish between left- and right-turning models.

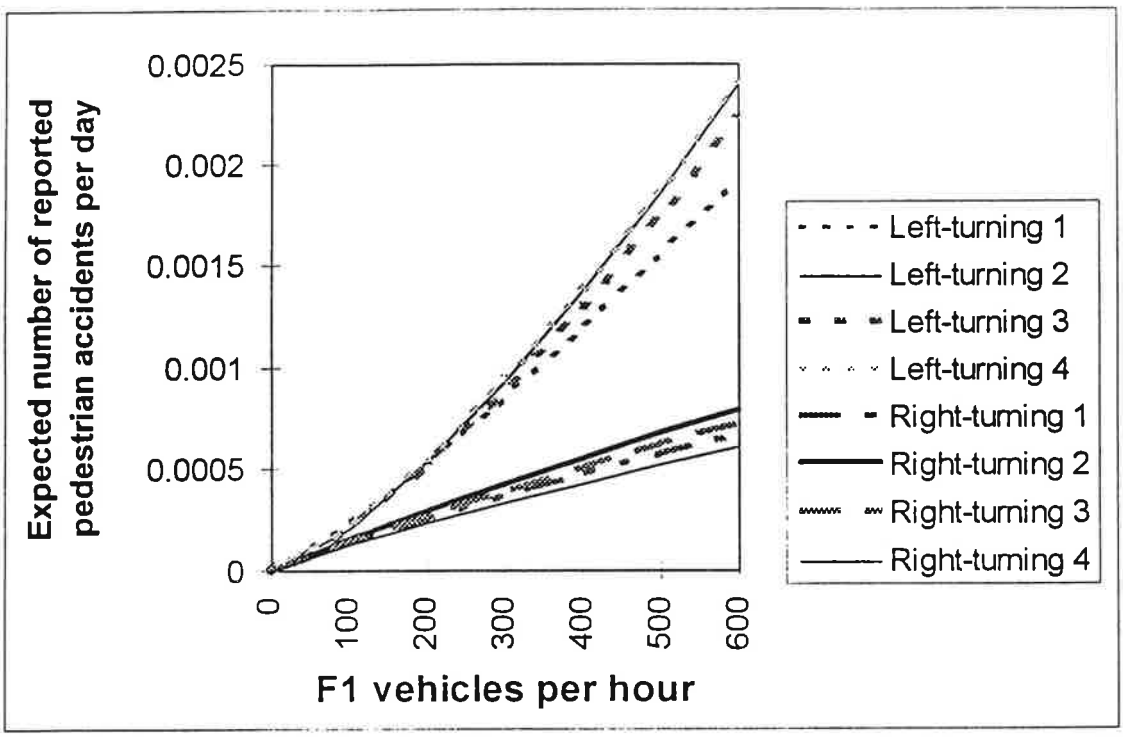


Figure 1. Estimates of E{m} for F_2 = 50 pedestrian per hour from the daily (1), a.m./p.m. (2), hourly (3) and 15-minute (4) models for left and right-turning turning vehicles

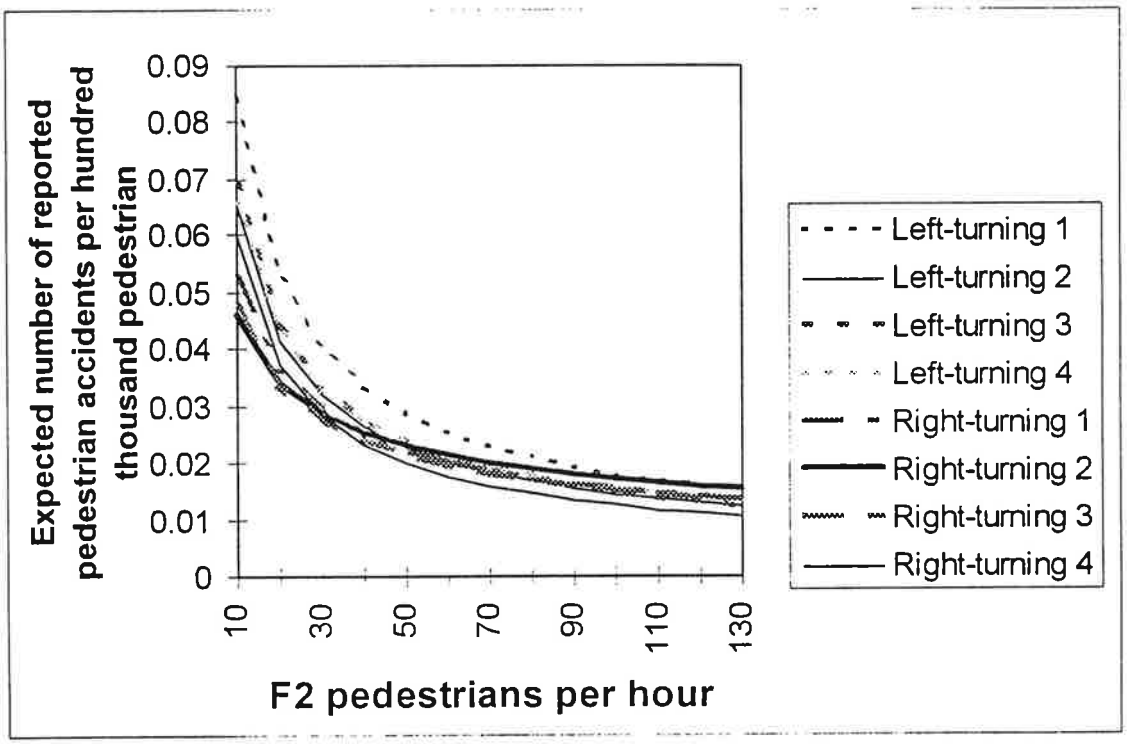


Figure2. Estimates of Expected number of reported pedestrian accidents per day for F_1 = *50 vehicles per hour* from daily (1), a.m./p.m. (2), hourly (3) and 15-minute (4) models for left and right-turning turning vehicles

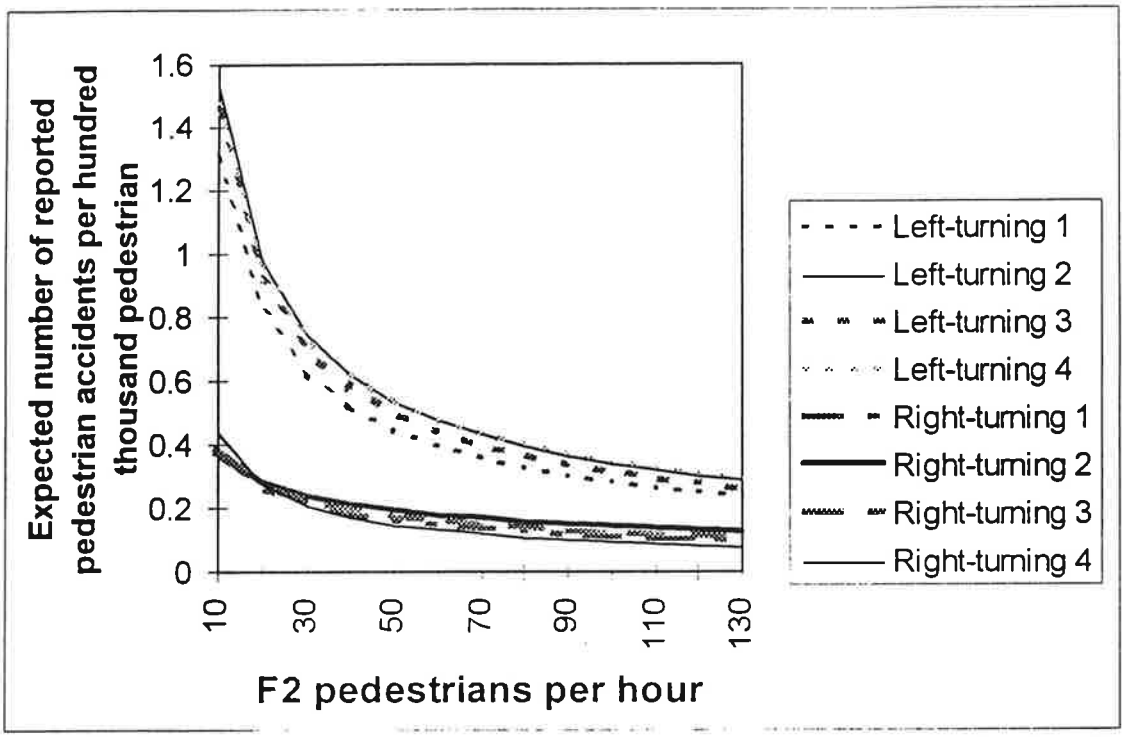


Figure 3. Estimates of Expected number of reported pedestrian accidents per pedestrian for F_1 = *500 vehicles per hour* from the daily (1), a.m./p.m. (2), hourly (3) and 15-minute (4) models for left and right-turning turning vehicles

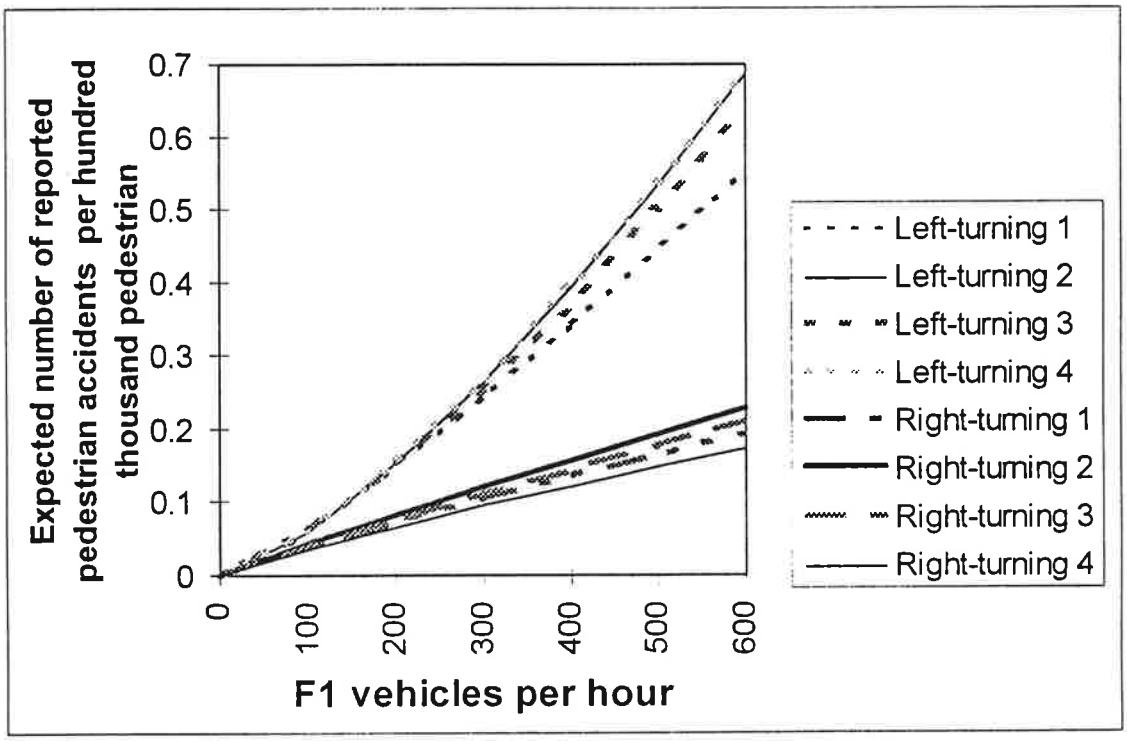


Figure 4. Estimates of Expected number of reported pedestrian accidents per pedestrian for F_2 = *50 pedestrian per hour* from the daily (1), a.m./p.m. (2), hourly (3) and 15-minute (4) models for left and right-turning turning vehicles

If risks for pedestrians are calculated as expected number of reported pedestrian accidents per pedestrian, risks are increasing when vehicle flow increases, see Figure 4.

SUMMARY AND DISCUSSION

We used a unique database providing pedestrian accidents and estimates of pedestrian and vehicle flows for the years 1983 - 1986 for approximately 300 signalized intersections in Hamilton, Ontario, Canada. Pedestrian safety at semi-protected schemes, where left-turning vehicles face no opposing traffic but have potential conflicts with pedestrians, were compared with pedestrian safety at normal non-channelized signalized approaches, where right-turning vehicles have potential conflicts with pedestrians.

Quaye, Leden & Hauer (1993) examine how two typical schemes for accommodating left-turning vehicles influences the safety for pedestrian. These are the semi-protected scheme described above and a permissive scheme, in which left-turning vehicles have to find suitable gaps in the opposing traffic. Semi-protected left turns tend to be safer for pedestrians at *low* vehicular flows. The opposite is true for high flows of left turning vehicles.
I explored four different ways of estimating hourly flows for left- and right-turning vehicles and fitted daily, a.m./p.m. hourly and 15 minute models to the data. Parameter estimates were affected by the time period used for flow estimation. However, parameter estimates seem to be much more affected by the traffic pattern (left- or right-turning traffic) even though approaches were selected so that the situation for left- and right-turning traffic should be similar (no opposing traffic, no advanced green or other separate phases and no channalization). Left-turning vehicles causes higher risks for pedestrians than right-turning vehicles, probably due to higher speeds caused by larger radius for left-turning vehicles. At *low* vehicular flows right turns and semi-protected turns tend to be equal safe for pedestrians, but right turns are safer for pedestrians than *permissive* left turns according to results quoted above.

If risks for pedestrians are calculated as expected number of reported pedestrian accidents per pedestrian, risks decrease with increasing *pedestrian* flows. Ekman (1996) has found for 95 non-signalized intersections in Malmö and Lund that the rate of pedestrian conflicts per pedestrian is not influenced by the pedestrian flow. According to Ekman this could be interpreted as follows: The individual pedestrian does not seem to benefit from presence of other pedestrians. Another interpretation is that the vehicle drivers do expect pedestrians, at least if pedestrian flow exceeds 30 pedestrians per hour. So in my case an explanation could be that vehicle drivers' alertness increases with increasing pedestrian flow.

If risks for pedestrians are calculated as expected number of reported pedestrian accidents per pedestrian, risks increase with increased *vehicle* flow. Ekman (1996) have found similar results for non-signalized intersections.

Flow fluctuates between and within each cycle of a traffic signal system. Flows are systematically higher at the start of the green period. However the time of the accident related to the start of the green period were not known, therefore it could not be studied how this influence the safety of pedestrian.

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REFERENCES

Aitkin, M., Baker, R.J., Clarke, M.R.B., Francis, B., Gilchrist, R., Green, M., Nelder, J.A., Reese, R.A., Payne, C.D., Slater, M., Swan, A.V., White, R., 1986. the Generalised Linear Interactive Modeling system: Release 3.77, Manual. Oxford.

Almuina, A.L., 1989. Pedestrian Accidents and left-turning vehicles at signalized intersections. Toronto, University of Toronto, Department of Civil Engineering. 116 p + 8 App.

Ekman, L., 1996. On the Treatment of Flow in Traffic Safety Analysis a non-parametric approach applied on vulnerable road users. University of Lund, Department of Traffic Planning and Engineering. Bulletin 136.

Hauer, E., C.N., J. & Lovell, J., 1988. Estimation of Safety at Signalized Intersections. Washington, D.C., Transportation Research Board, Transportation Research Record 1185, p. 48 - 61.

Hauer, E., Persaud, B.N., Smiley, A. & Duncan, D., 1991. Estimating the Accident Potential of an Ontario Driver. Accid. Anal. & Prev. Vol. 23, pp. 133 - 152.

Leden, L., 1993. Estimation of safety . Some theoretical considerations applied to pedestrians'safety at signalized intersections.

Maher, M.,J., 1989. Fitting Predictive Equations to Accident Data when there is uncertainty in the Traffic Flow Estimates. London, PTRC, 17th Summer Annual Meeting, University of Sussex 11 - 15 September 1989. Traffic Management and Road Safety. P. 171 - 181.

Maycock, G. & Maher, M., J., 1988. Generalized Linear Models in the Analysis of Road Accidents - Some Methodological Issues. Crowthorne, Transport and Road Research Laboratory. Personal Information. Working Paper. 8 p.

Quaye, K., Leden, L. & Hauer, E., 1993. Pedestrian Accident and Left-Turning Traffic at Signalized Intersections. Toronto, University of Toronto. Safety Studies Group. 18 p.

Computer simulation of traffic conflicts

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Introduction

The task of traffic conflicts computer simulation appeared because using traditional empirical traffic conflict methods was at some cases very difficult or impossible. There are such cases as traffic safety evaluation of new road projects, road reconstruction projects or long road sections. It is a very actual problem because safety evaluation of road projects has a key function.

At the beginning we knew that computer simulation of traffic conflicts has adventures and disadventures. The using of this method is very cheap. One computer experiment with simulation model is 10 till 1000 times cheaper comparing with empirical experiment. And this method is more objective because the identification of traffic conflicts is realized during simulation experiments according to input definition and not dependant on observer opinion But the quality of computer simulation of traffic conflicts is very dependant on the adequacy grade of the traffic flow simulation models. That is why we had to work out complicated simulation models, which describe the traffic flow as the moving and interaction of individual driver-vehicle units. This way of system description was achieved by desaggregated simulation models. We determine these models as the models built on the formal basis on the formal basis, proposed by Buslenko (1978) (partly constant aggregations), however, completed with the decision of some tasks (Siljanov, Tonkonozhenkov, 1996)

In the present article we will consider some results of the solution to these tasks related to simulation of traffic conflicts (the other results were described by Siljanov, Tonkonozhenkov, 1996) and will concentrate on two examples: for traffic flow simulation model on two-lane rural roads with oncoming traffic and for four-lane motorways which have two lanes in each direction.

Conceptual model on the interaction of drivers and conflicts in the traffic flow

The working out model on the interaction of drivers and conflicts in the traffic flow is based on the determining the special situations. We determine such situations as situations, where drivers can change their opinion on the road situation, regime or trajectory of movement. In the intervals between the special situations we assume, that all parameters presenting all drivers and vehicles on the simulated road section remain constant and the occurring of each situation corresponds to the leapingly changes of driver-vehicle units parameters, i.e. the determining of special situations is very important for the modelling. In the course of traffic conflicts simulation two groups of special situations were exposed:

Group 1. There are situations, related to the effect of vehicles moving in the same direction, same lane and road parameters on the vehicle movement (group 1); these situations are common to all mixed traffic flow simulation models in as far as they do not take into account the effects of vehicles on the neighbouring lanes and can be used as unifying unit in different models. At the first stage of investigations we assumed that these situations cannot be a main reason for the traffic conflicts because drivers can change their vehicle moving parameters as regards the moving parameters of the vehicle ahead and there are no reasons to sharp and abrupt braking (we didn't take into consideration such situation where drivers can be diverted from the road situation observation or can not "feel" the distance etc.). That is why we will not consider these special situations here.

Group 2. There are situations, modeling interaction of vehicles, situated on different lanes and (or) moving in a different (opposite) directions. These situations are connected with processes of forecasting and drivers decision making and also with mistakes during these processes, which can lead to traffic conflicts. Determining situations in this group and the reactions of drivers to them depends on concrete traffic control scheme on the lanes and that is why we use for each traffic flow simulation model the individual set of special situations. The important feature of worked out schemes on special situations for desaggregated models (fig. 1 - 2) is taking into account the characteristic features of every driver-vehicle unit. This is achieved by determining the characteristic distances (i.e. the distances which could correspond to one of the special situations), taking into account vehicle speeds (V_i, V_{i-1}; i - vehicle number for which a situation occurred, i-1 - the nearest vehicle ahead number on the same lane); vehicle types (TA_i, TA_{i-1} - passenger cars, light trucks, medium trucks, heavy trucks, trailers, buses); driver types (TD_i - mild (1), normal (2), aggressive (3)). These indexes are used below in the situations description. Another necessary attributes are determining the critical speed differences between interacting vehicles D taking into account the driver types, vehicle types, vehicle speed. This parameter is used for simulation of the choice of the speed by the movement after the vehicle ahead, for the overtaking possibility judgment etc.

Very important feature of presented schemes is taking into account the individual driver-vehicle system attributes when calculating speed value V, which could be maintained by drivers on the condition, that there are no vehicles ahead (block V, the algorithm for block V work was described by Syljanov, Tonkonozhenkov, 1996) and when checking the driver's possibility to start and complete overtaking or to change lane (block OVER; two results of the block OVER work mean: YES - driver decides to overtake; NO - driver refuses to overtake).

Group two situations for two-lane roads with oncoming traffic. The schemes for this group are presented in fig.1 (j - nearest oncoming vehicle on the neighboring lane).

Situation 1. Departure of vehicle i and nearing oncoming vehicle j ("tail & tail" position). In this situation the driver nimbler i have no more the vehicle number j as nearest oncoming vehicle and will judge, whether the new gap in the oncoming traffic flow is enough for the overtaking.

Situation 2. The appearance of the gap D' in a traffic flow of same direction before vehicle i-n which is enough for placing vehicle i on its proper lane after overtaking of the group of n vehicles. The value D' is calculated by a function:

$$D' = D_2 + L_i + D_{\min}, \qquad (1)$$

where: D_2 - safety distance between vehicles i and i-n at the end of overtaking (Netzer, 1966); L_i length of vehicle i; D_{min} - minimal safety distance between vehicles i and i-n-1.

By occurring of this situation driver i have a new favorable situation for the overtaking of group of n vehicles due to the return to his lane after the overtaking and will judge whether he can overtake whether he can overtake this group due to other conditions.

Situation 3. Sight distance went up to value S', enough for making a safe overtaking, i.e. at the moment of the incident the following condition is observed:

$$a \cdot X_i + b = S', \tag{2}$$

where: a and b - constant coefficients (road section characteristics), determining the function of sight distance for driver i on vehicle's i coordinate X_i (the distance between its front edge and the start point of the simulated road, measured through the road axis). The values a and b depend on the type of vehicle i. The critical value S' is evaluated through the working of the submodel on drivers overtaking judgment (block OVER)

Situation 4. Overtaking (i) and leading in the group of overtaken vehicles (i-n) equaled ("head & head" position). Empirical investigations showed, that this point is a critical point where the overtaking driver usually make a decision about the further way of his overtaking. That is why two variants of driver's reaction on the occurring of this situation are simulated: driver i can under corresponding conditions "prolong" overtaking (new leader of the group of overtaken vehicles among the further moving vehicles is chosen) or continue overtaking on the previous (at the start of overtaking) determined overtaking scheme.

Situation 5. The overtaking driver i is convinced, that from the closeness of oncoming vehicle the continuation of overtaking is dangerous. Simulation possibility of such situation makes such provision that during the simulation of driver's checking the possibility of overtaking (block OVER, see below) inaccuracy by driver in judgment overtaking parameters (time and distance T_o, S_o, required to overtake) and speed of oncoming vehicle (V_j) is considered. In this way the driver's inaccuracy in judgment of overtaking parameters is simulated by correcting actual values T_o and S_o; driver's inaccuracy in judgment of the oncoming vehicle speed - through substitution in the resulting condition in order to determine overtaking possibility not of actual speed value of oncoming vehicle which at the moment of overtaking beginning the driver is usually not able to identify (specify due to special visual perception in respect of the objects moving apart), but the kind of speed value which the driver "expect" when making a decision to overtake - potential speed V_p (Tonkonozhenkov, 1987). This function is expressed in the form:

$$S_o' + V_p \cdot T_o' < D, \tag{3}$$

where: D - distance between vehicles i and j at the moment of the driver's judgment;
S_o', T_o' - corrected values S_o and T_o.

Situation 5 could occur in a case where $V_p < V_j$ (underestimation), but the distance between the overtaking and oncoming vehicles (D) decreases to value D' determined by the following equation:

$$D' = (S_o' - s) + V_p(T_o' - t), \tag{4}$$

where: s,t - respectively distance and time through which the vehicle i passed from the moment of overtaking start till situation 5 occurs.

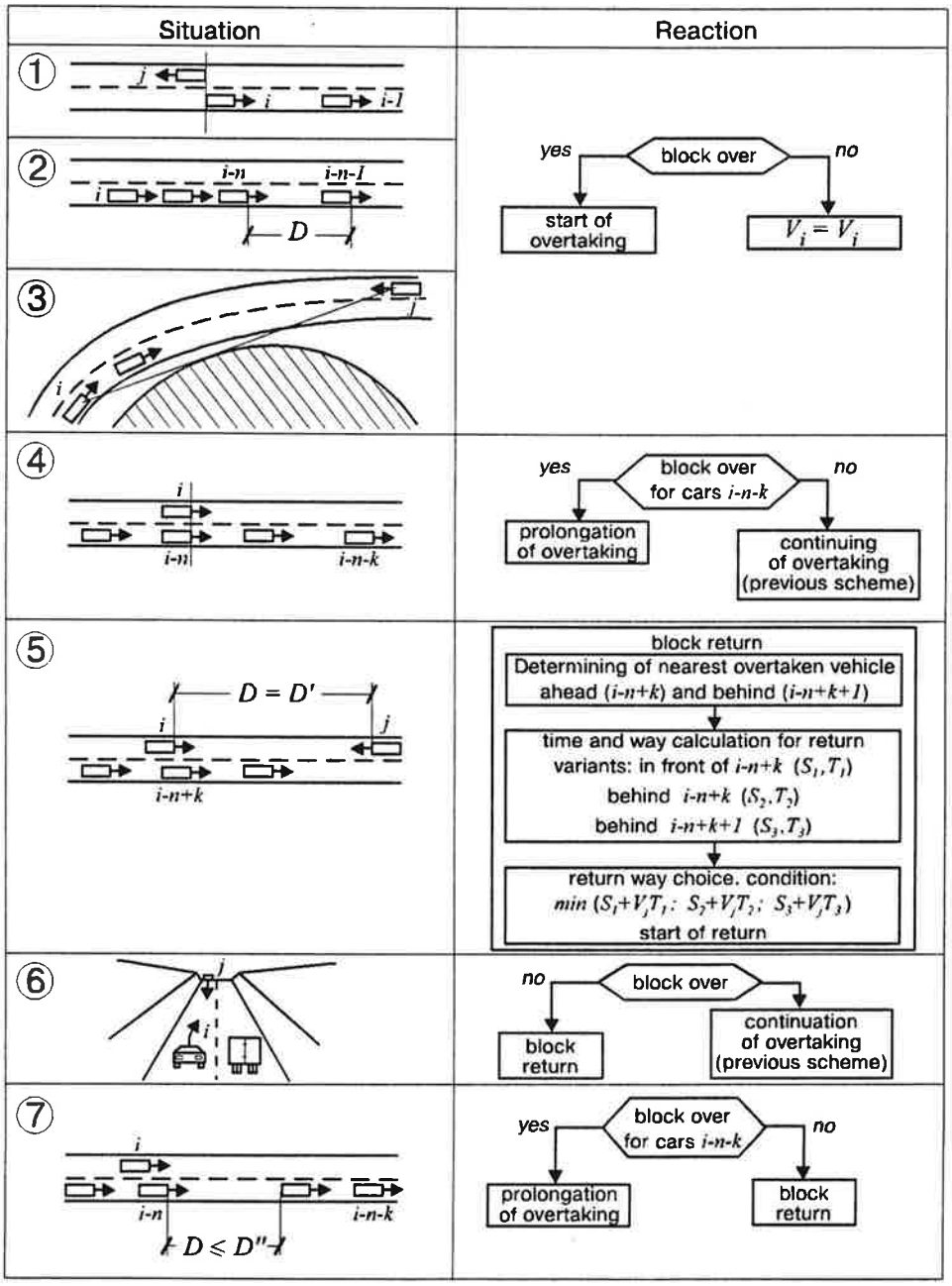


Fig. 1. Schemes on special situations in second group for two-lane roads with oncoming traffic

The occurrence of such situation calls for measures to avoid a collision, i.e. this is a conflict situation. Three possible kinds of conflicts are displayed: vehicle *i* returns to its lane in front of vehicle *i-n* (there is a reduction in safety distances between the vehicles *i*, *i-n* and *j*, however overtaking is carried up to the end); vehicle *i* returns to its lane using one of the gaps between the overtaken vehicles moving after the vehicle *i-n* and before vehicle *i*-1 (partial overtaking); vehicle *i* returns to its lane after vehicle *i-1* (a failed attempt to overtake).

Situation 6. The appearance of oncoming vehicle within the visual area of overtaking driver. A situation can occur for all those drivers who did not see the oncoming vehicle at the moment of the start of overtaking. Here the driver *i* will choose one from four possible variants dependent from the road situation: he can continue to overtake in according to his previous scheme or change his movement and trajectory parameters in according to variants described for the situation 5 (three possible variants of conflict situations)

Situation 7. Decreasing the distance between the leader of overtaken vehicles (*i-n*) and vehicle *i-n*-1 up to value $D = D''$, which is less than minimal distance required for safety return of overtaking vehicle *i* to its lane at the end of overtaking. In this situation driver *i* have to choose the safest variant: he can change his previous overtaking scheme and move further to overtake following vehicles or he can return to his lane in spite of the new distance in front of the leader in group of overtaken vehicles. Both variants can lead to the traffic conflicts, which are described above.

The block OVER has a key function for the traffic conflicts simulation. This submodel simulate the forecasting of the road situation development, the drivers evaluation of the road situation and decision making process. It works as follow (fig. 2):

- Selecting leading in the group of overtaken vehicles (number *i-n*). It is taking into account the distance between the vehicles *i* , and *i-n* and their speed values and also the speed value, at which the vehicle *i* will move at the end of overtaking. In such way is determined the potential aim of the driver *i*. Then the potential movement parameter of vehicle *i* are compared with actual movement parameters of vehicle *i-n* - as a result we determine, whether the driver *i* has a desire to overtake this vehicle group. Evidently the submodel can stop here its work (overtaking refusal).
- Calculation time and distance *To* and distance *So* required for the overtaking of the group from *n* vehicles follows. Overtaking may occur in different, among others the changing road conditions and that can influence the traveling of overtaking and overtaken vehicles during the overtaking. Because of that, the simulation of vehicles *i* and *i-n* movement forecasting during the overtaking is used. For this simulation four special situations are determined and time of occurrence of these situations is calculated. There are following situations: overtaking vehicle *i* reaches the end of the road section (change in road conditions is possible); leader in the group of overtaken vehicles (*i* - *n*) reaches the end of the road section; the vehicles *i* and *i-n* equaled (head & head position - the overtaking driver will determine the way of return to his lane); overtaking vehicle *i* completes the overtaking and returns to his lane before the vehicle *i-n*. After the occurrence of first, second and third situations the change in vehicles parameters take place according to the conceptual models on the reactions to these situations; by the occurrence of the fourth situations the parameters of potential overtaking of *n* vehicles are ready.

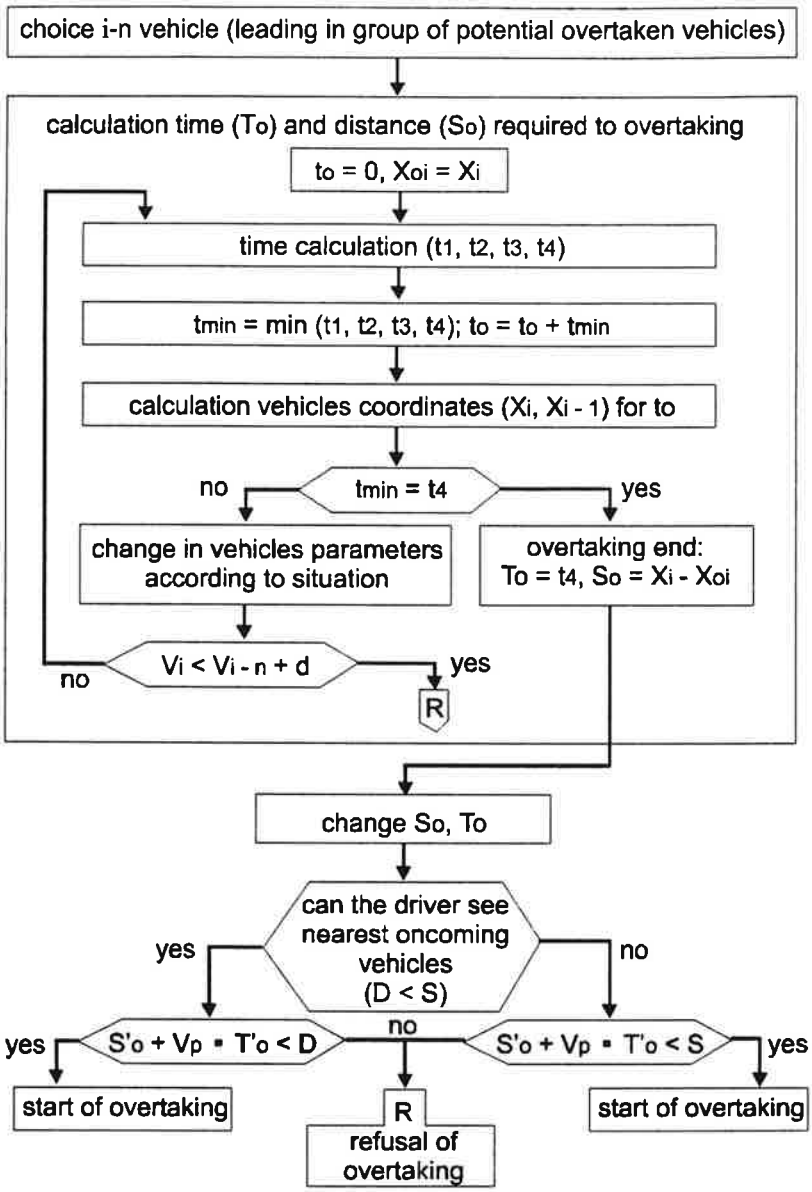


Fig. 2. General scheme for simulation of driver judgement of the overtaking possibility on two-lane roads (block OVER)

- After determining actual parameters *So* and *To* correction of their values follows in the light of inaccuracy of theses parameters, made by the overtaking driver; the grade of theses mistakes is dependent on the grade of movement parameters changing during the potential overtaking;

- The issue about starting overtaking is solved by using function 3 of two cases : for oncoming vehicle within the driver's sight distance and outside it (in both cases instead of actual oncoming speed value the potential speed value *Vp* is used; it takes into account, that the driver *i* is not able to estimate the speed value of oncoming vehicle at the start of overtaking).

Group two situations for four-lane motorways. Schemes for simulation this group of situations for four-lane motorways with median dividing lane and two lanes for traffic in every direction are shown in fig. 3. The vehicle involved in the situation is noted by num-

ber *i*; the nearest vehicle ahead in the neighboring lane is given the number *in*; the nearest one following at the back - *in+1*. The vehicle speeds are expressed as V_i, V_{jn}, V_{Jn+1}; their coordinates - as X_i, X_{jn}, X_{Jn+1}. , their lengths - as L_i, L_{jn}, L_{jn+1}.

In determining situations it was assumed, that a change in lanes with the aim of increasing speed and to overtake the vehicle(s) moving ahead on the same lane, is determined as an overtaking. A change in lanes not backed up by the aim to increase speed but freeing the lane to faster moving vehicles behind is counted as a change in lane (this maneuver can be accomplished only by the vehicle moving from the left lane to the right-hand one). Simulation of checking overtaking and change in lanes possibility is carried out by the block OVER. Following group two situations for four-lane motorways are simulated (fig. 3):

Situation 1. The distance between the vehicles (*i*) and (*in*) rose to value D_1 at which there is possible overtaking (or change in lanes) for vehicle *i*. For vehicles moving in the right lane overtaking possibility is checked for all vehicles, the speed of which is limited by the vehicle ahead (*i-1*). For vehicle *i* moving in the left lane, checking overtaking possibility is done only for some drivers ("aggressive" one, $TD_i = 3$), who allow the prohibited overtaking from the right. For drivers moving in left lane and do not belong to the type $TD_i = 3$, change in lanes possibility is checked. Here it is carried out in the following cases: if vehicle *i* is traveling out of the zone of influence (*De*) by vehicle ahead (*i-1*) or speed, which he can maintain (*V*) is less than that of vehicle *i-1*. This scheme is also used for simulation the drivers reaction to the occurrence the below described situations.

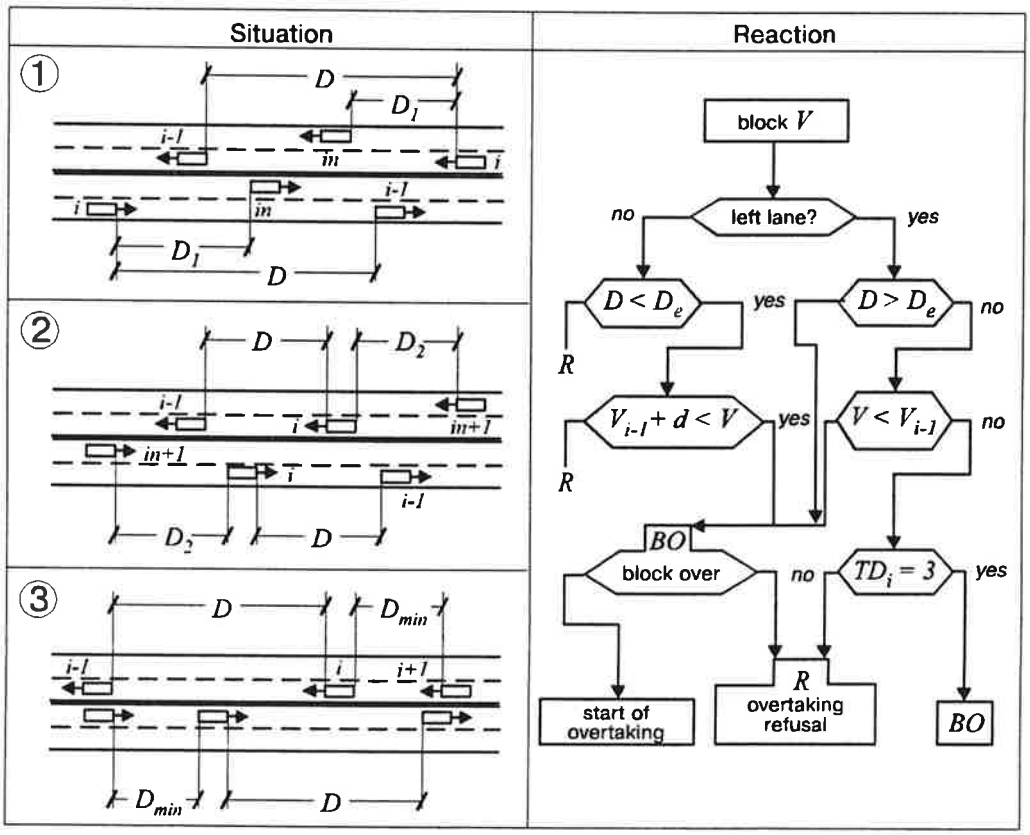


Fig. 3 Special situations schemes in second group for four lane motorways

Situation 2. The distance between vehicles (*i*) and (*in +1*) increased up to value D_2, at which driver *i* can begin overtaking (changing lane).

Situation 3. Driver *i*, moving in the left lane notices a fast moving vehicle behind (*i +1*), driving on the same lane. This situation occurs at the moment when distance between vehicles *i* and *i +1* decreases to the value D_{min}. It is assumed, that under definite conditions driver *i* can change to the right lane leaving way for the vehicle behind.

Block OVER which simulate drivers overtaking (change in lanes judgment) has some features comparing with the submodel OVER for two-lane rural road but the general approach is the same. To consider, that driver *i* at the moment of overtaking possibility judgment can only approximately judge the speed value of vehicle *in+1* , it is accepted, that at that moment he should compute his speed as potential value *Vp*.

$$V_p = V_{in+1} + p \qquad (5)$$

Where: *p* - value of inaccuracy of the vehicle *in+1* speed judgment from the driver *i* (random value). For the modeling the cases, where overtaking (change lane) necessitates a braking of vehicle *in+1* it is assumed, that some drivers by overtaking possibility judgment consider, that the maneuver may necessitate a braking of vehicle moving behind on the neighboring lane, but the deceleration will do not exceed the value a_p (this random value is one of the drivers characteristics) Safety condition for maneuver lies in the fact, that at the moment when the speeds of vehicles *i* and *in+1*are equaled (maximum closeness of vehicles *i* and *in+1)*, the distance between them will be not less than the border-line value *Dmin.*

Adequacy test

For the adequacy judgment of the presented simulation models were employed the comparing output parameters of the real and simulated traffic flows for the same input parameters. Input parameters comprise of: traffic volume and composition by vehicle types and brands in every lane; loading distributions for different vehicle types; road parameters, traffic control scheme. This method is applied on the availability of all above mentioned input data.

As an example illustrating this method of adequacy evaluation comparison of traffic conflicts distribution for real and simulated vehicles on different sectors on 1.5 km road stretch is below described. That was a four-lane motorway which has two lanes in each direction. All the simulated road parameters and traffic control scheme, data on traffic composition by vehicle types and brands and vehicles loading distributions corresponded to the data obtained from the observation on the actual road.

Table 1

section	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
model	2	2	1	2	2	4	6	8	6	14	20	14	14	14	6	8
real	2	2	2	2	3	4	8	9	7	16	22	14	16	12	6	6
range	2.5	6.5	10.0	13.5	18.5	25.5	36.5	51.0	65.5	87.5	123.5	158.0	186.5	213.5	231.5	244.5

$Z = -0.8$ ($< Zt$)

The results of comparison of traffic conflicts distributions on the observation spots for one of time intervals which was 2 hours long is shown in table 1. Adequacy test was based on the checking up of the hypothesis - that the selection of output model and actual system data belongs to one aggregate and was carried out with the use of Monney-

Whitney criterion, described by Shannon (1978). In most given case it was seen that the calculated criterion value Z proved less than the border value Z_t, i.e. adequacy test in most cases gave a positive result.

Application examples for research into traffic conflicts distribution

The developed simulation models for traffic conflicts distributions investigations consider in detail the individual driver-vehicle characteristics, road conditions, behaviour nature of drivers and drivers interactions under different road conditions. That is why in order to carry out simulation experiments it is essential adventure to have minimum input data.

The developed models can be used for research into traffic conflicts distributions on concrete roads, taking into account their individual characteristics. This possibility is important for evaluation of new road projects, road reconstruction projects or traffic control measures on concrete roads.

The practical use of traffic conflicts simulation is demonstrated by the results of computer experiments with the traffic flow simulation model on a four-lane motorway, which has 1.5 km length and an about 1-km long upgrade with 3-4.5 percent slope (fig. 5). There were 10 % of trucks in the traffic flow. The total time of simulation experiment was 7 hours.

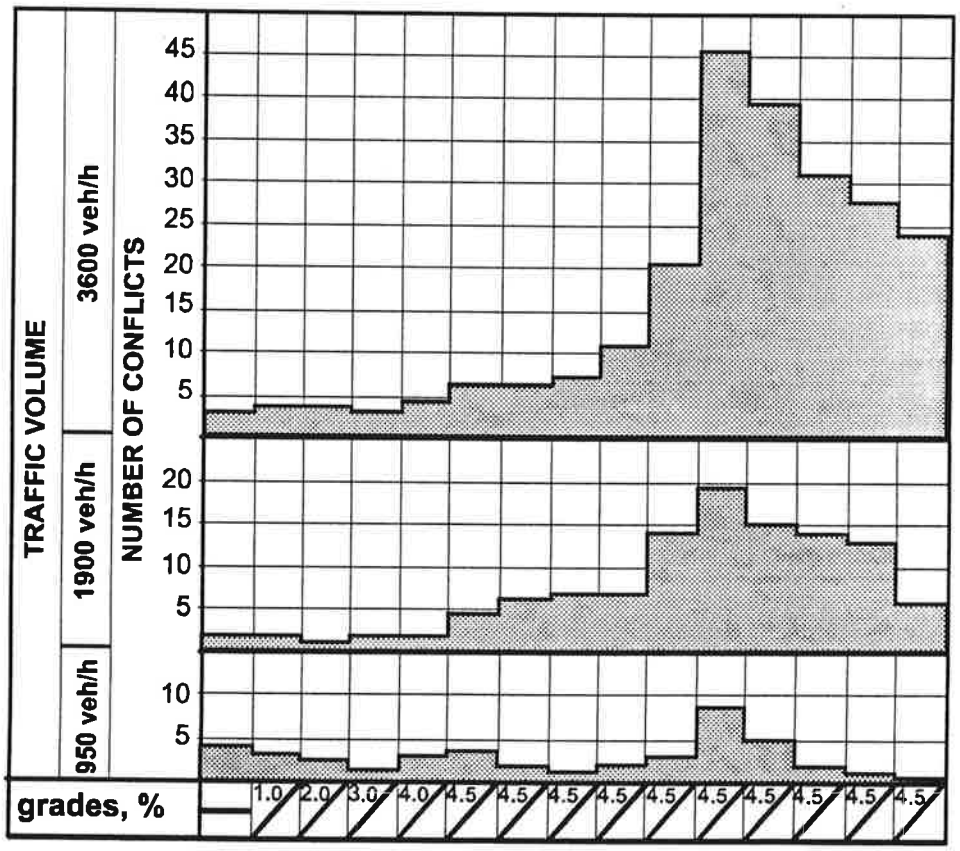


Fig. 4. Traffic conflicts distribution on an upgrade of four-lane motorway (one direction) dependent on traffic volume (total time of simulation experiment is about 7 hours)

It is interesting to see, that the sector with traffic conflicts concentration don't move by traffic volume change and is situated at the 400 - 500 m distance from the top of upgrade and the number of conflict situations increases when the traffic volume increases. The same tendencies were observed at the empirical way.

Another example demonstrates the results of computer experiments with the traffic flow simulation model on a two-lane rural road stretch, which had 1.5 km length, an about 800 m long upgrade with about 4.5 % medians slope, one horizontal curve with 300 m radius and limited sight distance. (fig. 6) There were 56 % of trucks in the traffic flow. Total time of the simulation experiment was 2 hours.

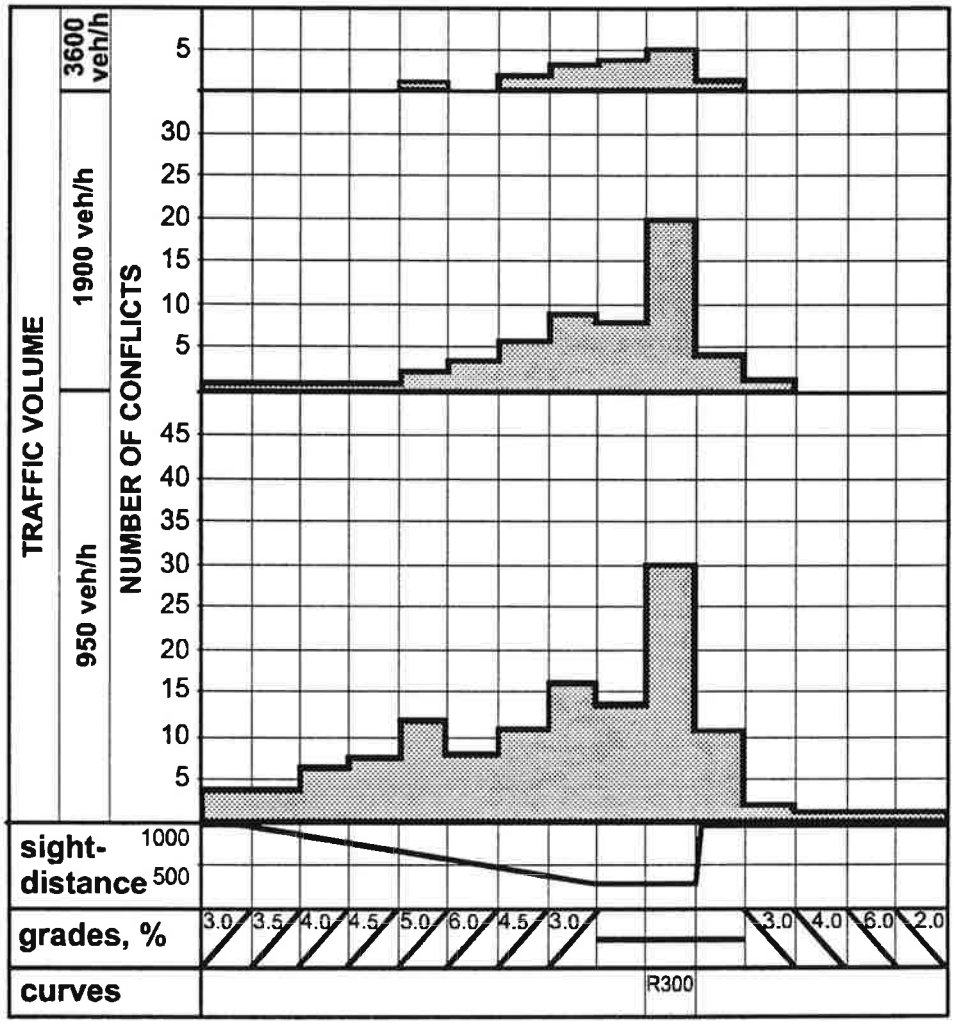


Fig. 5. Traffic conflicts distribution two-lane rural road with oncoming traffic (one direction) dependent on traffic volume and traffic volume distribution on lanes (total time of simulation experiment is about 2 hours)

It was noticed, that the road has an evident potential black spot, which is situated on the curve and the road is most dangerous by significant differences in traffic volume on lanes. Here it was the 650/280 traffic volume distribution.

Conclusion

The described method of traffic conflicts computer simulation considers in details the features of each driver-vehicle unit and their interaction in the traffic flow under different road conditions. The important result of this is the possibility to investigate the traffic conflicts distributions on the roads depending on the changes in the input parameters i.e. road parameters and traffic flow volume and composition. That gave room for such investigations, which would be very difficult to carry out by means of other methods. Using of described method proved effective for investigations into traffic conflicts distributions on concrete roads with their individual features, what is very important for the traffic safety evaluation of new road projects, road reconstruction projects or evaluation of traffic regulation measures.

References

Buslenko, N.P. (1978). *Simulation of Complicated Systems*. Nauka Publ. House, Moscow. (Бусленко, Н.П. (1978). *Моделирование сложных систем*. Наука, Москва).

Netzer, M. (1966). Der Ueberholvorgang auf Landstrassen unter Beruecksichtigung der Verkehrssicherheit. *Strassenbau und Strassenverkehrstechnik*, **50**.

Shannon, R. (1978). *The Simulation of Systems: Art and the Science*. Mir Publ. House, Moscow. (Шеннон, Р. (1978). *Имитационное моделирование ситем: искусство и наука*. Мир, Москва).

Tonkonozhenkov, O.I. (1987). Drivers' Search for Overtaking Possibilities and Overtaking Vehicle Movement. *MADI Proceedings*, **34**, pp. 66-74. (Тонконоженков, О.И. (1987). Поиск водителями возможностей для обгона и режимы движения обгоняющих автомобилей. *Труды МАДИ*, **34**, стр. 66-74).

Silyanov, V.V, Tonkonozhenkov, O.I Research into mixed traffic flow characteristics by means of simulation. *Proc. of the 13th International; Symposium on Transportation and Traffic Theory*. Pergamon, Lyon, 1996, pp.539-560

A method to analyse the traffic process in a safety perspective

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1. Introduction

This research has its basis in the Swedish Traffic Conflicts Technique (TCT) developed at the Department of Traffic Planning and Engineering in Lund, Sweden (Hydén, 1976). Validation studies have shown a clear relationship between serious conflicts and police reported injury accidents. The work with serious conflicts is a big step forward towards more satisfactory analyses of traffic safety problems. The analyse of serious conflicts can however not claim to be the universally prevailing tool when it comes to describing all safety related aspects. It has therefore become necessary to expand the conflict concept and look into the whole traffic process in order to find parameters explaining the occurrence of risky situations. If we would be able to find these parameters in the "normal" traffic process then we would have a more favourable and efficient situation when making safety evaluation studies and proposing measures. Taking into consideration the possibility of using a more automatic method to collect traffic data, this approach would be very attractive.

2. Traffic process

What do I mean by *the traffic process in a safety perspective*? The traffic process can be seen as a continuum of events. A continuum of events that build up the whole traffic system. These events are all more or less related to safety. Traffic is interaction. All events in the traffic process contain some kind of interaction but of course to varying extent. There is interaction between road users and there is interaction between the road user and the road and vehicle environment. The interaction contains communication. The quality of the interactive behaviour depends on the quality of the communication. The level of communication is influenced by factors like;

- expectancies: a priori knowledge and situational information
- attitudes, etc.

A safe traffic environment presupposes good interactive behaviour and good communication. The opposite, in an unsafe environment, the interactive behaviour and the communication are bad. Accidents indicate serious breakdowns in the interaction between road users or between the road user and the road and vehicle environment. It is therefore quite natural to approach traffic safety by analysing the occurrence of the traffic accidents and their consequences, in order to find clues to prevent future accidents.

There are however many problems connected to the use of accident data for traffic safety evaluation. Accidents are rare events. For the local everyday traffic safety work, it is not sufficient to use accident data only. To produce reliable estimates of traffic safety; very often additional information is needed. There are also difficulties with the recording of accidents. Not all accidents are reported and the level of reporting is unevenly distributed with regard to type of road users involved. Vulnerable road users are for instance heavily under represented in the police accident statistics compared to what hospital registrations and other

studies show. The behavioural or situational aspects of the events are not covered by accident data. It is for example very hard to determine underlying factors causing the accident only by reading the accident record, or even by making in-depth analysis on accidents. In the latter case a major complication is that it is too expensive to obtain data that will be representative enough. The need for surrogate or complementary methods to accident analysis is consequently high.

Work with the Swedish TCT has shown that one type of unsafe interaction called serious conflict, exactly like the accident, contains a breakdown in the interaction. The serious conflicts have furthermore an established relationship to accidents. It has also been possible to distinguish the serious conflicts from other types of interactions, in terms of closeness in time. If we believe in the continuum of safety related events, then there must be many more interactive events, besides the accidents and the serious conflicts, that have a correlation to safety.

The following hypothesis were set up:

- There is a continuum of safety related events

- i.e. some of the factors that make a situation turn out as an accident or a serious conflict might also be found in more normal interactions. There is safety information to be found in "normal" interactions
- That these interactions will give us information about the behaviour pattern and characteristics of comfortable, safe passages and the contradiction - passages that are less comfortable, more unsafe
- That there might be a boarder of how close (in time?, in space?, in both time and space?) it is comfortable, safe, to pass other road users (depending on types of road users involved).
- That there is a relationship between the quality, in some dimension, of the interactions and accidents / serious conflicts

The conclusive hypothesis is therefore that the quality of the interactions is the basis if we really want to talk about traffic safety and how to induce proper traffic safety work. Today, traffic safety work lack theories that connect behaviour to safety. Or more correctly, there are many theories but most of them have never been validated with regard to safety. Speed is an exception. Studies have shown a firm relationship between speed and safety (Pasanen, 1992). On the other hand there are for example no theories about how changed level of vehicular speed changes the crossing behaviour among pedestrians and by that the safety situation. This is due to lack of principles for safe interactions. The future challenge, where my work hopefully can be a part, is to define and study the principles of safe interaction. The outcome will hopefully be a help towards more qualified traffic safety work.

3. The safety pyramid

In Oslo 1977, 33 researchers from 12 nations agreed upon a common definition of a conflict: 'a conflict is an observational situation in which two or more road users approach each other in space and time to such an extent that a collision is imminent if their movements remain unchanged'. When describing the relationships between different safety related events in the traffic process the pyramid concept was introduced (Hydén, 1987), see Fig 1. According to this concept the different levels in the pyramid can be seen as a severity scale i.e. the

probability for an police reported injury accident is constant within the level and increases towards the top. This severity scale is accomplished by applying the TA / Speed-dimension i.e. the Conflicting Speed and the Time to Accident-value (TA-value). The Conflicting Speed (here after just called speed) is the speed of the road user taking evasive action, in the moment just before the start of the evasive action. The Time to Accident (TA-value) is the time that remains to an accident from the moment that one of the road-users starts an evasive action with the assumption that they otherwise had continued with unchanged speed and direction. The ICTCT calibration study in Malmö (Grayson,1984) showed that all calibrated TCTs work according to the same severity scale even if they in other dimensions differ.

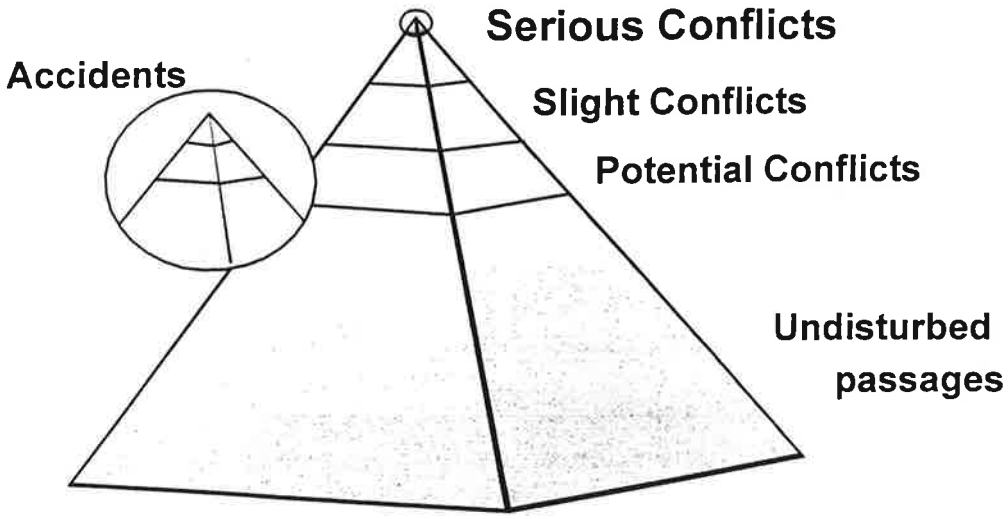


Figure 1 The pyramid - the interaction between road-users as a continuum of events (Hydén, 1987)

The validation studies carried out have shown a relationship between police reported injury accidents (the very top of the pyramid) and serious conflicts (the level beneath the property only accidents). The question is now what happens if we go to the levels below the serious conflicts and look at the traffic process. The levels below the serious conflicts are called slight conflicts and potential conflicts. These are conflicts with much higher TA-values than the serious conflicts. If we go all the way down to the base of pyramid, we'll find the "undisturbed" passages. What do we include in this term? If the rest of the pyramid is based on TA / Speed values, it is logical to assume that this is true for the "undisturbed passages" as well. Is there a limit in the TA / Speed - graph that separates the potential conflicts from the "undisturbed passages"?

If we have a safety pyramid based on the TA / Speed concept, where do all the other TCTs fit, that work according to other concepts? It is quite easy to accept that for instance the PET situations with very low margins also have safety relevance even though there is never collision course. (The PET-value is the time measured from the moment the first road-user leaves the potential collision point to the moment the other road-user enters this point.) There might be a possibility that we actually are talking about a number of severity scales based on different concepts / safety principles. Perhaps if all these severity scales were put together we would obtain the whole continuum of safety related events. What I am trying to

say is that there are other safety dimensions in traffic that are not necessarily based on the TA / Speed concept. I do however stick to the TA / Speed concept since I believe that the first approach towards better knowledge about the safety content in "normal" interactions must go through the relationships that we do know something about. What we do know is as I mentioned before that there is a relationship, on the basis of TA / Speed, between accidents and serious conflicts. My approach is to follow this concept down in the pyramid and analyse whether I am able to find other situations that have a connection up in the pyramid.

An other reason for keeping to the pyramid concept is the finding in a validation study of the Swedish TCT (Svensson, 1992). The basis for that validation study is a report by Hauer and Gårder (1986) where they "define safety of an entity to be the expected number of accidents (by severity) occurring on the entity per unit of time". "Thus when the validity of the TCT is questioned, one is in fact asking whether the estimate of the aforementioned expected value in some sense is 'valid'". Hauer and Gårder suggest the following operational definition of what 'validity' means: "A technique (method, device) is 'valid' if it produces unbiased estimates the variance of which is deemed to be satisfactory". In the validation study by Svensson it was found to be better, it produced lower variances, when the expected number of accidents for a unit was based on three days of conflict studies than on one year of accident data. The registration procedure of conflicts in the Swedish TCT has changed a bit over the years. At that time when the data for the validation study was collected, there was a subjective severity rating for the conflict observers to fill in for each registered conflict. The subjective severity rating represents the observers personal estimate of the probability that the conflict could have ended up in an injury accident. A subjective rating in the interval 3 to 6, indicated a serious conflict or an accident. A subjective rating of 2 indicated a potential conflict and the subjective rating of 1 indicated some kind of closeness. The best results for the Swedish TCT were achieved when conflicts with subjective rating 2 to 6 were included. That is when the more serious potential conflicts also were included. We had previously anticipated that the most favourable results for the Swedish TCT would come about when only serious conflicts were included in the data set. Why didn't it turn out this way then? There are two possible answers to this question. 1) The simple fact that the increased data also improved the results 2) The content in the additional data, conflicts with subjective rating 2, correlated to safety. The "truth" could very well be found in both answers. To clear up the concept an additional analysis was carried out - all registered conflicts, also those with subjective severity rating 1, were included. That is the data increased and the severity of the conflicts decreased. Now the variance in the expected number of accidents increased. The conclusion could be that the potential conflicts, subjective rating 2, also contain safety related information but that there is a limit when the interactions start to be less safety relevant. But the conclusion could also be that since the intention never was to collect interactions of subjective type 1, this type might be incomplete in the set of data. The finding however suggests that it might be wise to move down in the safety pyramid, below the serious conflicts. How far down in the pyramid it is reasonable to go, further research hopefully will give us clues about.

Studies with the Swedish TCT show that the accident to conflict ratio differ between types of intersections and between road user categories. The accident to conflict ratio is for instance different in signalised and non-signalised intersections. Depending on road user types involved, the accident to conflict ratio is about 1.5 times higher in signalised intersections compared to non-signalised intersection. This implies different shapes of the

safety pyramid depending on type of intersection. Thus, the pyramid in the signalised intersection have a more pointed top compared to the non-signalised intersection. Which pyramid shape would be optimal for safety? When we are talking about optimal traffic safety solutions we imagine solutions that neither produce injury accidents nor serious accidents. This implies that the top of the pyramid is cut off. The hypothesis about a safety continuum will still exist even without the accidents and the serious conflicts. But what will the rest of the pyramid then look like?

4. Interactions

Definition of interaction
In my case an interaction involves two road users. Interaction with the road and vehicle environment as such is excluded i.e. single interactions are excluded. In a way it can still be seen as an explanatory variable to why the interaction between road users perform in a certain way. If, for instance, it comes to explaining why the severity distribution of the interactions differ between two intersections, the variable "interaction with the road and vehicle environment" might be an interesting variable.
An interaction is a situation with collision course. Collision course = the road users would have collided if the they had continued with unchanged speed and direction. This implies that there is some kind of noticeable evasive action, like in the conflict definition. The evasive action is not necessarily always as dramatic as in the serious conflicts. It can also have the character of adaptation i.e. evasive action to avoid "something more serious".

The procedure to register interactions is the following:
The evasive behaviour is analysed for each vehicle or pedestrian approaching the beforehand selected part of a site. At the point when the road user starts to slow down or accelerate, the road user is projected with the speed it had just before. For each road user taking evasive action there is only one counterpart. On the other hand may one road user be counterpart to several different road users taking evasive action.

With the Dutch TCT (Risser&Tamme, 1987; van der Horst&Kraay, 1985) there is found to be a significant correlation between PET and speed of the oncoming car, that has right of way and safety. A situation with a certain PET and a higher speed is more severe than a situation with the same PET and lower speed. So both the ICTCT Calibration study in Malmö (Grayson, 1984) and the definition in DOCTOR of a recordable event suggest that events that are close enough in time and space ought to be included when describing severity. The ICTCT Calibration study found MTTC (Minimum Time To Collision - a continuos measuring during the duration of a conflict) to be the most important factor in explaining common severity for the different Traffic Conflicts Techniques. The second most important factor was found to be the minimum distance between the road users. The DOCTOR both includes PET (Post Encroachment Time) situations and situations with TTC (Time To Collision). This implies content of safety information in situations that are close enough in time and space without necessarily having collision course.

What is registered?
At the department we are traditionally very concerned with the traffic safety of vulnerable road users. It was therefore quite clear from the beginning that I wanted to look at interactions involving vulnerable road users. It was also very tempting to try to include the Kaivokatu-Keskuskatu - intersection in Helsinki, Finland where accidents have been video-recorded (Pasanen, 1993). By including this intersection I would get the opportunity to describe the relation between accidents and interactions. Since the focus in the Kaivokatu-Keskuskatu - recording was set on pedestrians, I chose to concentrate the interaction studies to pedestrians / motor vehicle situations. I consequently decided to register all situations between motor vehicles and pedestrians having collision course. Besides these situations, due to the above mentioned reasons, I also wanted to include some situations where there is no objective collision course. The criteria for these situations are:
Evasive action - might be interpreted as having subjective collision course. The road user takes evasive action as if there was a real collision course.
Closeness in time and space - might be interpreted as PET situations with small margins.

How to make sure that all these interactions are included in the registration?
One possibility would have been to enlarge the footprint for the vehicle and/or the pedestrian: If I had used the semi-automatic image processing system developed at the Department then I could have enlarged the footprint. The footprint is a rectangular box projected from the road user to the road surface. The size of the footprint is set at the beginning of each analysis. The footprint then keeps the size in terms of road length units but changes in image length units as it moves around in the picture. The size of the footprint is set manually and could accordingly be reduced or enlarged in relation to the true size. With an enlarged footprint, situations with no, but just about, collision course would be registered as if there were collision course. Depending on how much the footprint was enlarged it would have been possible to decide how big the margins would be for a situation to be detected as one with collision course. This presupposes though that both road users are followed through the intersection and that the coordinates are picked for both road users every 0.08 seconds. This process is fairly time demanding and was not thought to be justified in my study.
What I have done instead is to further analyse situations without collision course but where the TA- value is up to 0.2 seconds from being a collision course. The first estimate is based on pedestrian speeds like 4.0, 5.0, 6.0 km/h. If I then get a close hit, PET, then I go back and see if it would have been collision course if the pedestrian had walked 0.5 km/h faster or slower. On top of this I have analysed as if the vehicles fill up the whole lane, from the kerb to the lane marking. If the pedestrian had just stepped out from the kerb when the vehicle had passed then it would have been collision course.
The major drawback with this way of analysing is that these values are speed dependent and I haven't taken that into account so far. Situations involving vehicles with higher speeds and that are close in time and space will to a higher extent not be detected compared to situations with slower driving vehicles. The situations including slow driving vehicles will be over represented in the sample. The reason is that the time for being in collision course decreases with both vehicle speed and pedestrian speed.

5. Shape of the safety pyramid

Now we have arrived to the part where I will try to justify the new approach. All interaction studies are carried out from video recordings, recorded during daytime, about 10 a.m. to 1 p.m.

I have looked at the following vehicle / pedestrian situations:
- Pedestrians crossing on a pedestrian crossing and straight on driving vehicles
- Pedestrians crossing on the same pedestrian crossing and right turning vehicles

At the following sites and times
- Kaivokatu-Keskuskatu- a signalised intersection in Helsinki, Finland (Pasanen, 1993). Video-recordings from the accident tapes and from recordings in connection to conflict studies 1995 - A total of 7 hours.
- Värnhemstorget - a signalised intersection in Malmö, Sweden, similar to the Helsinki intersection. Video-recordings from 1996 and 1997 - A total of 13.5 hours.
- Djäknegatan-Baltzarsgatan - an intersection with obligation to give way to the right, in Malmö, Sweden. Video-recordings from 1996 - A total of 12 hours.

The first analyse was to see if the two situations, vehicles driving straight on and vehicles turning right, would produce different distributions with regard to TA / Speed. That is, would these situations produce different shapes of the safety pyramid. This analyse is from one pedestrian crossing at the signalised Kaivokatu-Keskuskatu intersection in Helsinki. The pedestrian crossing chosen is independent of recent changes in the intersection (as far as I can tell) and is furthermore the pedestrian crossing closest to the camera. The latter is very important since the camera is placed very high up in a building and I must be able to register also small evasive actions. The two situations compared are:
SF/P - Straight forward driving vehicles and the pedestrians taking evasive action
T/P - Turning vehicles and pedestrians taking evasive action

The TA / Speed graph is divided into 22 severity sections (numbered 1 to 22 in Fig 2). The sections are parallel to the curve that sets the border between serious conflicts and potential conflicts. According to the Swedish TCT all events within the same section have the same severity. Situations in section 1 have the highest severity and then the severity decreases as the section-number increase. Section 1 to 5 are serious conflicts and 6 to 22 are slight and potential conflicts. The border between serious conflicts and potential conflicts is consequently between section 5 and 6 i.e. at TA=0.5 sec (on the X-axis) when the Conflicting speed=0 (on the Y-axis).

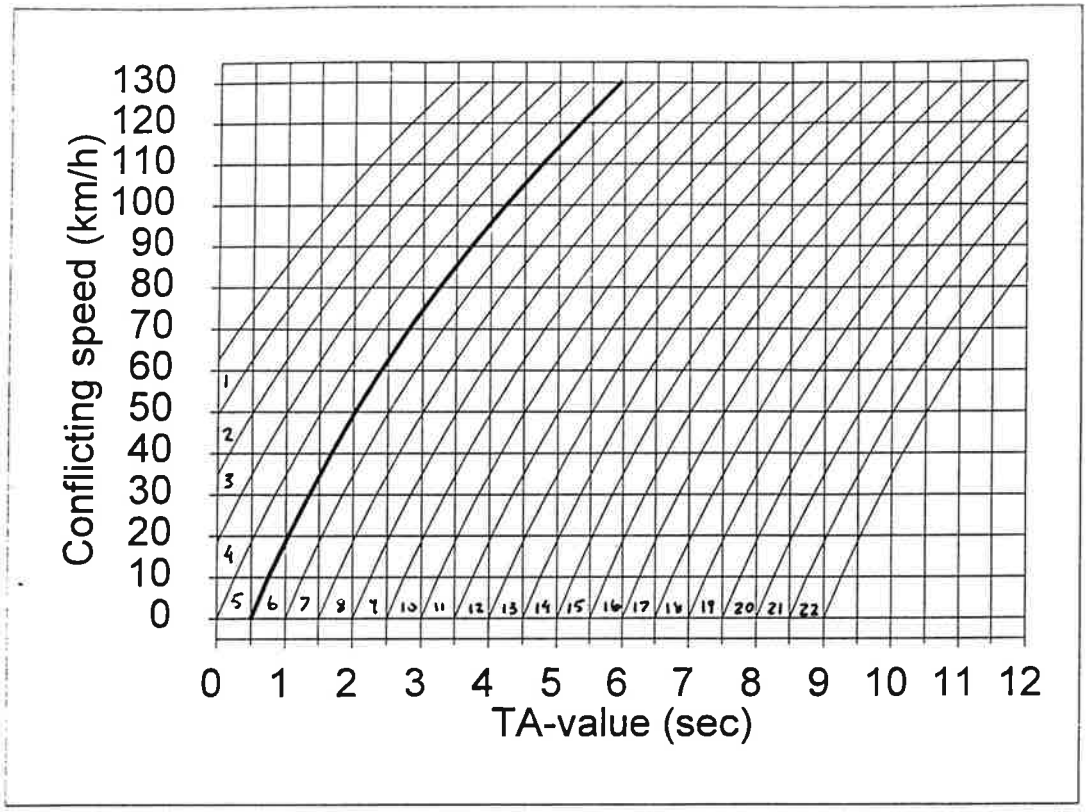


Figure 2. The TA / Speed graph divided into 22 parallel sections, numbered 1 to 22.

The TA / Speed values of the T/P interactive situations (see Fig 3) start in severity section 5, that is this type of situation contains serious conflicts. There are no serious conflicts registered for the SF/P situations (see Fig 4). The TA / Speed values of the SF/P situations start to appear in section 7. The number of interactions in the severity sections then increase as the severity decreases and reach a breakpoint in section 9 for T/P and in section 12 for SF/P. After the breakpoints the number of interactions in the sections start to decrease.

The similarity in the distributions of the T/P situations and the SF/P situations was tested with the Kolmogorov-Smirnov test (Marascuilo & McSweeney, 1977). The null hypothesis is that the distributions are identical. With a two-sided test, KS(maximum difference)=0.31 > KS(132,168;0.99)=0.19, i.e. the null hypothesis was rejected on the 99% significance level. The test showed that the distributions are not identical.

The finding suggests that there is a difference in the shape of the safety pyramid for the T/P and SF/P situations. From the accident recordings in this intersection (that I'll come back to further down) I know that injury accidents of both types have occurred. If I didn't have that information I would faulty assume that SF/P situations are safer since the interactions produce higher TA-values than the T/P situations. I could have drawn the completely misleading conclusion that the very top of the pyramid (injury accidents and serious conflicts) is cut off in the SF/P pyramid. But since I do know that there are injury accidents at the top of both pyramids the conclusion should instead be that the SF/P pyramid should be more pointed at the top compared to the T/P pyramid. The accident to conflict ratio should be higher for the SF/P situations that is these situations are more unsafe.

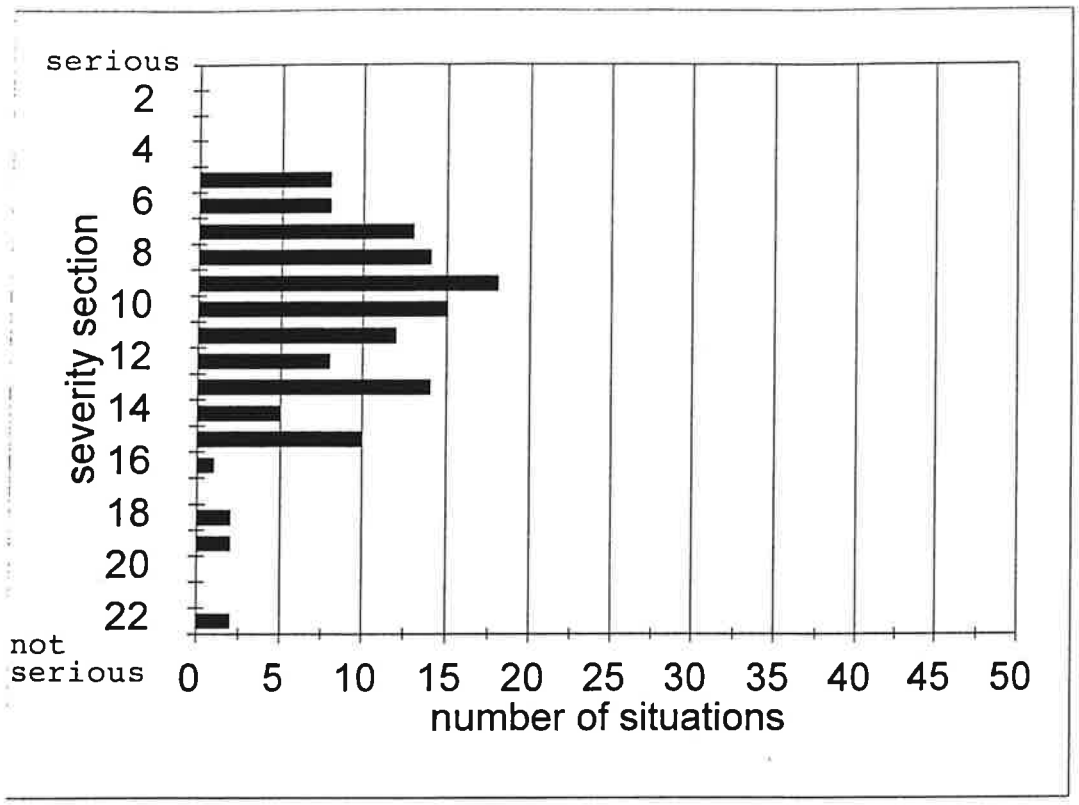


Figure 3. Interactions belonging to T/P = Turning vehicles and pedestrians taking evasive action. The distribution of interactions in the 22 TA / Speed related sections.

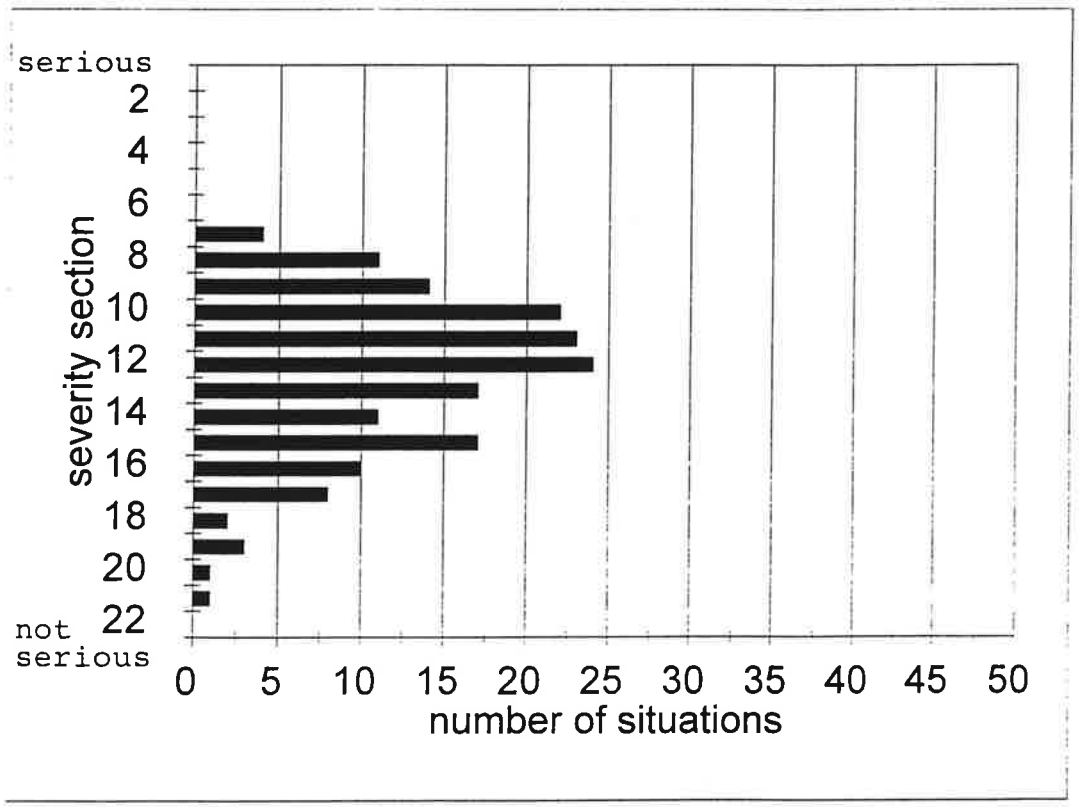


Figure 4. Interactions belonging to SF/P = Straight Forward driving vehicles and pedestrians taking evasive action. The distribution of interactions in the 22 TA / Speed related sections.

The total lack of serious conflicts in the SF/P situations is quite interesting. One explanation could be that the serious conflicts in SF/P interactive situations do exist but are very rare. If the SF/P situations just were studied long enough the serious conflicts would also start to appear. An other explanation could be that the safety outcome of this type of situation can not be explained by the TA / Speed concept. A third explanation could be that the SF/P situations to a higher extent occur at other times of the day than I have observed .

The search for an explanation reminded me of an other study where we during one week in the summer of 95 video-recorded the Kaivokatu-Keskuskatu intersection. The aim was to conduct conflict studies from these recordings. The intersection was video-recorded during 19-20 hours per day, starting at 7 a.m. and finishing at 2 or 3 a.m. the following morning. So far 39 hours, two "day-and-night periods", have been analysed with regard to conflicts. The result was 9 conflicts of the type turning vehicle at conflict with crossing pedestrian, out of which 6 were regarded as serious. They were evenly distributed over the registration period. Conflicts of the type straight forward driving vehicle in conflict with crossing pedestrian were 4 in number. "All" occurred during the night, i.e. 11 p.m. to 3 a.m., and were regarded as serious conflicts.

The four years of accident data, that I so far have access to, include 2 accidents of type turning vehicle and pedestrian crossing and 2 accidents of type straight forward driving vehicle and pedestrian crossing. In both accidents with the turning vehicle, the pedestrian and the vehicle proceed when the signal is green. It is worthwhile to note that the vehicles here have an obligation to give the pedestrians right of way. The 2 accidents with the straight forward driving vehicles include a pedestrian crossing at red. 3 of the 4 accidents occurred during the night, in this case between midnight and 2 a.m.

The issue why I seem to lack the serious conflicts in the interactive data set for SF/P situations must be sorted out thoroughly when this paper is written. But from the discussion above there seems to be more information to achieve if it was possible to conduct interactive studies during longer periods and during other times of the day. The main problem with this approach would be that it is almost impossible to register interactions during the night. Small deviations in speed and direction are not observable due to the poor quality of the pictures. It is considerably easier with the serious conflicts since the evasive actions are so much more distinct. The most important task right now is to combine all information about accidents, conflicts and interactions for the Kaivokatu-Keskuskatu intersection. Information like speed, TA-value and severity in terms of injury. From this it would be possible to determine likely shapes of the whole safety pyramids, ranging from injury accidents at the top to interactions with low severity at the bottom.

References

Grayson G.B. ed; The Malmö Study. A calibration of traffic conflict techniques. Institute for Road Safety Research SWOV, Leidschendam, the Netherlands, 1984.

Hauer E, Gårder P; Research into the Validity of the Traffic Conflicts Technique. Accident Analysis and Prevention. Vol 18, No. 6, pp471-481, 1986.

van der Horst R, Kraay J: The Trautenfels Study: A diagnosis of road safety using the Dutch conflict observation technique DOCTOR. Leidschendam, the Netherlands. 1985.

Hydén C; En konfliktteknik för riskbestämning i trafiken. Department of Traffic Planning and Engineering, Lund, Sweden. 1976.

Hydén C; The development of a method for traffic safety evaluation: The Swedish Traffic Conflicts Technique. Department of Traffic Planning and Engineering, Lund, Sweden. 1987.

Marascuilo L, McSweeney M: Nonparametric and Distribution-Free Methods for the Social Science. California, USA. 1977.

Pasanen E; Driving speeds and pedestrian safety; a mathematical model. Publication 77. Helsinki University of Technology, Finland. 1992.

Pasanen E; The Video Recording of Traffic Accidents, 1993:4. Helsinki City Planning Department, Finland. 1993.

Risser R, Tamme W: The Trautenfels Study. Kuratorium für Verkehrssicherheit, Wien, Austria. 1987.

Svensson Å; "Vidareutveckling och validering av den svenska konfliktteknikken". Further development and validation of the Swedish Traffic Conflicts Technique. Department of Traffic Planning and Engineering, Lund Sweden.1992.

AN ASSESSMENT OF SOME CAUSAL MODELS TO EXPLAIN DRINKING-DRIVING INTENTION

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SUMMARY

We discuss the results we obtained in a work which intended to assess the adequacy of several models to represent the relationships among the variables included in the hypotheses of the application of the *Theory of Reasoned Action* to drinking and driving intention, and also some 'external' specific variables -past drinking and driving behaviour, and current alcohol consumption-. A correlational design was used. 620 young drivers were interviewed using a questionnaire which had been built to assess all of the variables, and several path analyses were performed.

INTRODUCTION

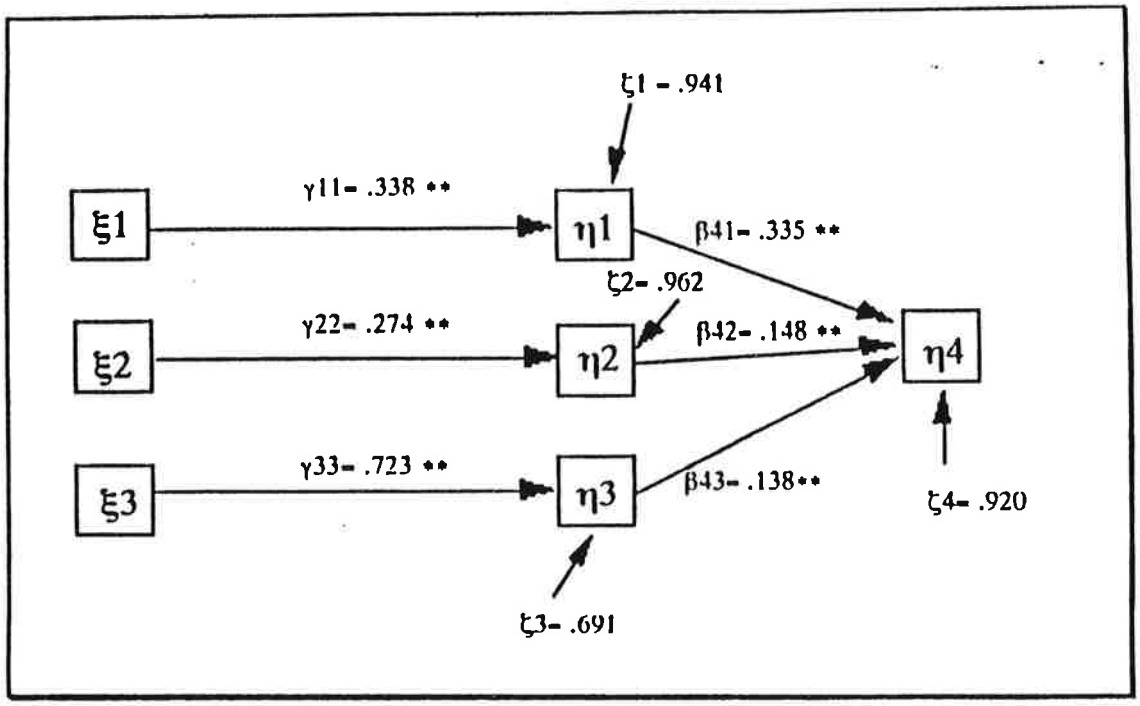
In another study (Carbonell, Tejero and Canet, 1996), results are presented of the evaluation of a model of causal relationships between the psychological variables which intervene in the intention to drive under the influence of alcohol sustained in the hypothesis of Fishbein and Ajzen, the Theory of Reasoned Action (Fishbein and Ajzen, 1975; Fishbein, 1980; Ajzen and Fishbein, 1980).

In this model (model A, see Figure 1) we stated that the attitude toward driving under the influence of alcohol ($\eta 1$), the intensity of the subjective norm in relation to this behavior ($\eta 2$), and the motivation to comply with this same subjective norm ($\eta 3$), were three factors which explained the intention to drive under the influence of alcohol ($\eta 4$), without the interaction of the latter two factors having a significant influence on the intention.

It was also stated that the attitude toward driving under the influence of alcohol was explained by one factor ($\xi 1$) which saturated significantly and in a positive way in the intensity with which the beliefs related to the risk of having an accident and the loss of control of the vehicle are maintained, and in a negative way in the beliefs related to the pleasure derived from carrying out this behavior, the time saved compared to taking some form of public transport, and the comfort of not depending on anyone and not having to worry about finding alternative means of transportation. Likewise, it was stated that the intensity of the subjective norm was explained by another factor ($\xi 2$) qualitatively different from the previous one, which integrated five normative type beliefs, related to the expectations the spouse, brothers and sisters, police/Civil Traffic Guard, relatives and friends have about the behavior of the subject in this situation, and whose measurement is also based on the confirmatory factorial analysis mentioned. Finally, it was stated that the motivation to comply with the subjective norm was explained by a third factor ($\xi 3$), qualitatively different from the two previous ones, that integrated five specific motivations to behave in accordance with the opinions of the spouse, friends, relatives, brothers and sisters and mother.

The results of the *path analysis* performed indicated that the global adjustment of the observed data to this model were not good (GFI=0.850 and AGFI=0.720), although all the hypothesized causal relationships were statistically significant ($p<0.05$). In any case, the amount of variance explained by the endogenous variables was, in general, low (15% in the case of intention).

Figure 1. Results obtained in the evaluation with path-analysis of model A (=p <0.01, ** = p <0.05).*



∑ ξ1: Beliefs about the consequences of driving under the influence of alcohol
∑ ξ2: Normative beliefs related to driving under the influence of alcohol
∑ ξ3: Motivations to comply with referents regarding driving under the influence of alcohol
∑ η1: Attitude toward driving under the influence of alcohol
∑ η2: Intensity of the subjective norm on driving under the influence of alcohol
∑ η3: Motivation to comply with the subjective norm on driving under the influence of alcohol
∑ η4: Intention of driving under the influence of alcohol
∑ ζn: residuals

Some studies carried out by other researchers have obtained results which indicated that certain relationships distinct from those included in the model could be relevant. For example, some authors have suggested that the attitude toward the behavior and the subjective norm are closely interrelated, contradicting the independence proposed for these variables by Fishbein and Ajzen (Miniard and Cohen, 1981; Shepherd and O'Keefe, 1984); some even present results which indicate that the subjective norm has a causal influence on the attitude toward the behavior (Brubaker and Fowler, 1990). Likewise, certain authors point out that the structure composed of the normative beliefs and the motivations to comply with the references has a causal influence on the attitude toward the behavior (Ryan, 1982; Shimp and Kavas, 1984; Oliver and Bearden, 1985; Brubaker and Fowler, 1990).

Here we attempted to determine which model of causal relationships between the variables hypothesized in the Theory of Reasoned Action optimizes the adjustment of our data to the model, at the same time that it increases the amount of variance explained of the behavioral intention. Third, we analyzed whether the addition of the variables previous experience with the behavior and intensity of the actual consumption of alcohol could improve the explanation of the intention. It has been argued that previous experience with the bahavior would directly influence the beliefs underlying the determinants of the behavioral intention (Schwartz and Tessler, 1972; Doll and Ajzen, 19929. Thus, empirical evidence exists which is favorable to the hypothesis that the customary intensity of alcohol consumption by an individual is a relevant factor in explaining the behavior of driving under the influence of alcohol (Wilson and Jonah, 1985), as well as in explaining certain beliefs related to alcohol and driving (Martens, Ross and Mundt, 1991).

Finally, the hypotheses we add to those stated in model A are the following:

a• The inventory of the consequences of driving under the influence of alcohol has a direct and positive influence on the intention to carry out this behavior.
b• The inventory of the normative beliefs on driving under the influence of alcohol has a direct and positive influence on the attitude toward driving under the influence of alcohol.
c• The inventory of the normative beliefs about driving under the influence of alcohol has a direct and positive influence on the inventory of the beliefs about the consequences of driving under the influence of alcohol
d• The inventory of the motivations to comply with the references has a direct and positive influence on the intensity of the subjective norm related to driving under the influence of alcohol
e• The inventory of the motivations to comply with the references has a direct and positive influence on the inventory of the consequences of driving under the influence of alcohol
f• The inventory of the normative beliefs about driving under the influence of alcohol would covariate with the inventory of the motivations to comply with the references
g• The experience with the behavior has a direct and significant influence on the intention to drive under the influence of alcohol
h• The experience with the behavior has a direct and significant influence on the beliefs about the consequences of driving under the influence of alcohol
i• The customary intensity of alcohol consumption has a significant influence on the intention to drive under the influence of alcohol
j• There exists a positive and significant relationship between the frequency with which one has driven under the influence of alcohol-experience with the behavior-and customary intensity of alcohol consumption
k• The customary intensity of alcohol consumption has a statistically significant influence on the attitude toward driving under the influence of alcohol.

METHOD

The sample used in this study consisted of N=620 subjects. All of the subjects were chosen because they regularly drive a motor vehicle to get around when going out for fun, from a representative sampling of 1500 subjects between 15 and 29 years of age and residents of the Valencian Community, obtained by means of a simple random sampling (51% women, 49% men). The median age of the subjects in the sampling turned out to be 23.34 years (typical deviation=3.67), and included 430 men (69.4%) and 190 women (30.6%).

The theoretical variables involved in the intention to drive under the influence of alcohol were evaluated by means of answers given by the subjects on a questionnaire made up of items developed following the guidelines of Fishbein and Ajzen. All of the items referred to a hypothetical situation in which the expression "under the influence of alcohol" was used to refer to feeling, at least, the following effects after having partaken of alcoholic beverages: the feeling of being slightly dizzy or light-headed, slightly blurred vision, certain difficulty in controlling body movements. The selection of the contents of the items (perceived consequences to driving under the influence of alcohol, and referents of relevance in the population studied) were empirically based, according to the results of a previous pilot study involving a sampling of 50 subjects and four dynamic groups with various other groups of 8 to 10 young people (Tejero, 1995). The previous experience with the behavior and the intensity of alcohol consumption were measured using self-reports.

The evaluation of all the hypotheses, as well as the global adjustment of the data observed to the stated models, was carried out by means of *path analysis*. To achieve this goal, the statistical packet EQS (version 3.0) was used (Bentler, 1989). Arbitrary estimation methods were chosen -AGLS- (Browne, 1982, 1984; Bentler, 1983a; Bentler and Berkane, 1985; Berkane and Bentler, 1987a; Shapiro and Browne, 1987; Bentler, 1989), given the marked asymmetry and curtosis of the distributions derived from our data for some of the variables.

Three distinct models were evaluated. Model B includes the hypotheses *a* to *f* as well as the hypotheses included in model A. Model C includes all the hypotheses included in model B, as well as

the hypotheses *g* and *h*. Model D includes all the hypotheses included in model C, as well as the hypotheses *i*, *j*, and *k*.

RESULTS

The results obtained in the evaluation of models B, C, and D are highly satisfactory. While in model A we showed that the adjustment indexes between the hypothesized model and our data did not allow us to arrive to a favorable conclusion with regards to this adjustment, these same indexes indicate that the three models adequately represent our data (in model B: GFI=0.983, AGFI=0.947, and X^2/d.f.=2.11; in model C: GFI=0.970, AGFI=0.916, and X^2/d.f.=2.89; in model D: GFI=0.967, AGFI=0.921, and X^2/d.f.=2.50). In addition, all of the *path coefficients* are statistically significant (as a minimum with $p<0.0005$), because of which all the postulated relationships between the variables included in each model receive empirical support (see Figures 2, 3 and 4).

Thus, in comparison with model A, any of the three models increases considerably the proportion of explained variance of the endogenous variables by the variables hypothesized as predictors. Models B, C, and D are distinguished from the Theory of Reasoned Action and the Theory of Planned Behavior, amongst other variations, because they state that the intention is directly determined not only by the attitude toward the behavior, the intensity of the subjective norm, and the motivation to comply with the subjective norm, but also by the beliefs about the consequences of the behavior, whose influence is considered only of an indirect nature in the models by Fishbein and Ajzen. In fact, our data indicate that the beliefs about the consequences of driving under the influence of alcohol is the factor which contributes to a greater degree to the explanation of the intention in this behavior, ahead of the attitude toward the behavior, and its contribution is able to increase the percentage of explained variance by more than twice as much, by 15% in model A, by 37% in model B, and by 38% in models C and D.

Another of the differences of models B, C, and D with respect to those of Fishbein and Ajzen lies in the fact that they state that the attitude toward driving under the influence of alcohol is directly influenced not only by the beliefs about the consequences of this behavior, but also by the normative beliefs related to the behavior. Our data confirm that there exists a tendency whereby the more referents perceived as contrary to the subject driving under the influence of alcohol, and the fewer referents perceived as favorable to his doing so, the more favorable is the subject's evaluation of this behavior. Furthermore, we found that the incorporation of this variable as a predictor of the attitude toward driving under the influence of alcohol almost doubles the percentage of explained variance of the criterion variable, which changes from 11% in model A to 21% in models B, C, and D.

Something similar occurs in the case of the variable intensity of the subjective norm, of which it is possible to explain 14% of its variance when we consider as its predictors not only the normative beliefs (models B, C, and D), which in model A explain 7% of the variance, but also the motivations to comply with the referents. Thus, it is confirmed that the normative beliefs about driving under the influence of alcohol have a direct influence on the beliefs about the consequences of driving under the influence of alcohol, in such a way that the more referents perceived as being against the subject driving under the influence of alcohol, and the fewer referents perceived as in favor of this behavior, the more positive consequences and the fewer negative consequences are perceived by the subject in this behavior. We also confirm that the motivations to comply with the referents has a direct influence on the beliefs about the consequences of driving under the influence of alcohol, so that the more motivated the subject is to comply with the referents, the more positive consequences and fewer negative consequences he perceives in this behavior. Specifically, the percentage of variance of the beliefs about the consequences of the behavior that is jointly explained by the two variables is 19%, slightly higher than the contribution of the normative beliefs.

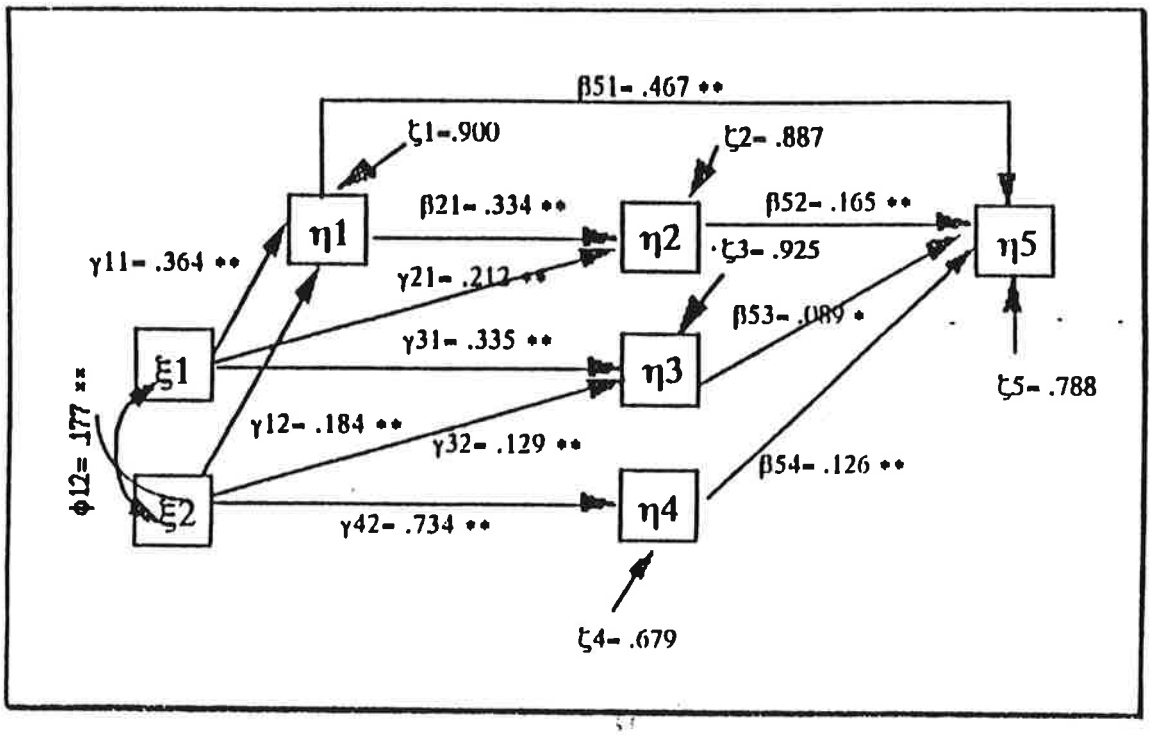
We also obtained empirical support for the hypothesis on the co-variation between the normative beliefs about driving under the influence of alcohol and the motivations to comply with the referents.

In the same way, it is confirmed that there exists a certain tendency where the more frequently the subject has driven under the influence of alcohol, the more likely is his intention to drive under

these conditions again in the near future. However, the additional contribution of the previous experience with the behavior to explain the intention to drive under the influence of alcohol is scant, in as much as the proportion of the explained variance of the intention changes from 37% in model B to 38% in Model C, and, in the same way as in model B, the beliefs about the consequences of driving under the influence of alcohol continue to be those that explain to a greater extent the intention in model C. Our data also confirm the influence of the experience with the behavior on the beliefs about the consequences of driving under the influence of alcohol, so that the greater the frequency with which the subject has driven under the influence of alcohol in the past six months, the more favorable is the inventory of the consequences of driving under the influence of alcohol. Although the magnitude of the additional contribution of this variable is small -going from 19% in model B to 23% in model C-, however, the experience with the behavior is the variable which provides the greatest relative contribution of the three hypothesized as potential predictors of the beliefs about the consequences of driving under the influence of alcohol.

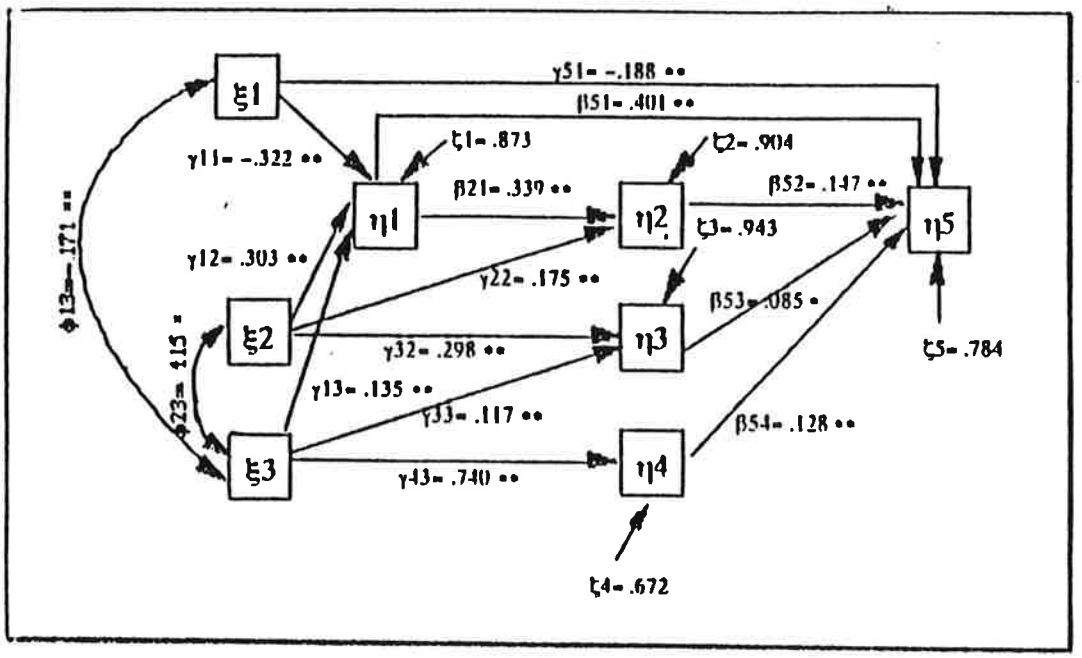
Finally, it is also confirmed that the greater the average amount of alcohol consumed daily by the subject, the more likely it is that the intention of the subject is to drive under the influence of alcohol. However, the percentage of the variance explained by the group of variables hypothesized as predictors of the intention continues to be 38%, so that the introduction of this new variable does not increase the amount of variance of the intention explained with respect to what was already explained by the rest of the variables hypothesized as predictors (model C). On the other hand, the intensity of the consumption of alcohol would covariate significantly with the experience with the behavior. Likewise, the intensity of alcohol consumption also has a certain influence on the attitude toward driving under the influence of alcohol, so that the greater the quantity of alcohol consumed daily, the more favorable is the attitude toward driving under the influence of alcohol.

Figure 2. Results obtained in the evaluation with path-analysis of model B (=p <0.01, ** = p <0.05).*



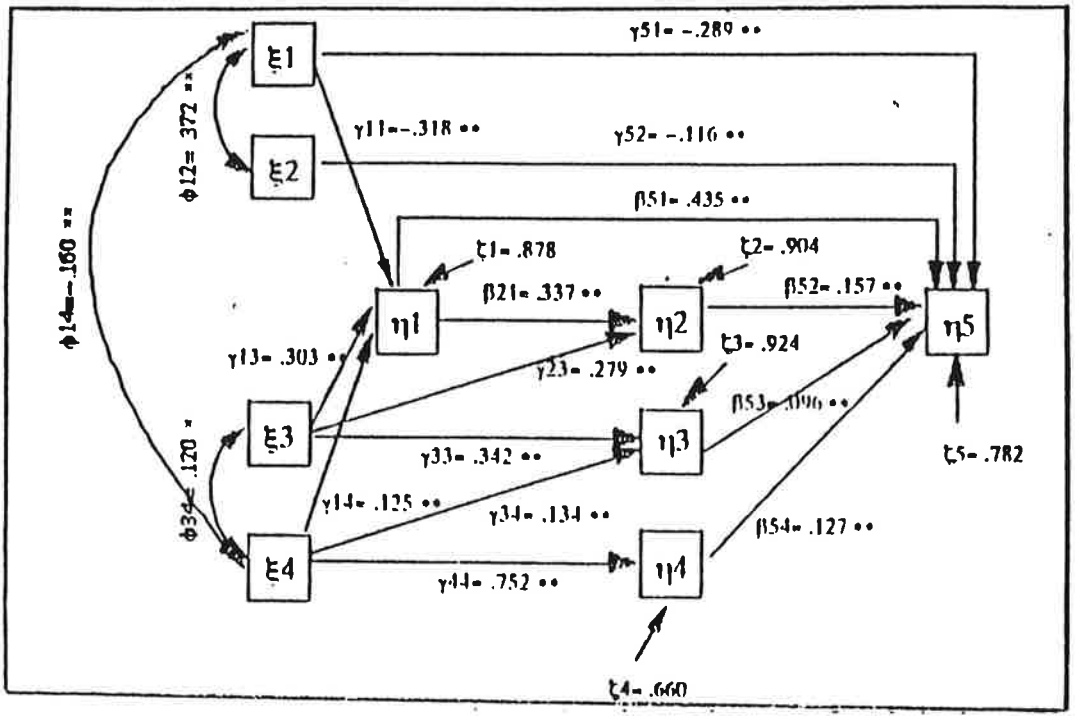
- ξ1: Normative beliefs related to driving under the influence of alcohol
- ξ2: Motivations to comply with the references in relation to driving under the influence of alcohol
- η1: Beliefs about the consequences of driving under the influence of alcohol
- η2: Attitude toward driving under the influence of alcohol
- η3: Intensity of the subjective norm on driving under the influence of alcohol
- η4: Motivation to comply with the subjective norm on driving under the influence of alcohol
- η5: Intention to drive under the influence of alcohol
- ζn: residues

Figure 3. Results obtained in the evaluation with path-analysis of model C (=p <0.01, ** = p <0.05).*



- ξ1: Experience with the behavior of driving under the influence of alcohol
- ξ2: Normative beliefs related to driving under the influence of alcohol
- ξ3: Motivations to comply with the references in relation to driving under the influence of alcohol
- η1: Beliefs about the consequences of driving under the influence of alcohol
- η2: Attitude toward driving under the influence of alcohol
- η3: Intensity of the subjective norm on driving under the influence of alcohol
- η4: Motivation to comply with the subjective norm on driving under the influence of alcohol
- η5: Intention to drive under the influence of alcohol
- ζn: residues

Figure 4. Results obtained in the evaluation with path-analysis of model D (=p <0.01, ** = p <0.05).*



- ξ1: Experience with the behavior of driving under the influence of alcohol in the last six months
- ξ2: Intensity of the customary alcohol consumption
- ξ3: Normative beliefs related to driving under the influence of alcohol
- ξ4: Motivations to comply with the references in relation to driving under the influence of alcohol
- η1: Beliefs about the consequences of driving under the influence of alcohol
- η2: Attitude toward driving under the influence of alcohol
- η3: Intensity of the subjective norm on driving under the influence of alcohol
- η4: Motivation to comply with the subjective norm on driving under the influence of alcohol
- η5: Intention to drive under the influence of alcohol
- ζn: residues

Prototypical scenarios, a means for describing traffic accident phenomena in road safety research and diagnostic studies.

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Abstract.

The concept of an accident 'scenario' (in France 'scénario' or 'scénario type') has been used since the late 80s in French research into road safety. An accident scenario can be defined as a prototypical accident process corresponding to a series of accidents which are similar in terms of the chain of facts and causal relationships found throughout the various accident stages. This concept provides a means of combining and generalizing the knowledge obtained from accident case studies, based on in-depth investigation methods or on detailed analyses of police reports. Applications of this concept are developed in both the field of traffic accident research and safety studies (diagnoses) in preparation for engineering measures or local safety policies. This paper presents the accident scenario concept, its theoretical background, the way it is used for safety research and studies, and the research work on this concept conducted by INRETS in co-operation with several Universities.

1 Scientific context

One of the research approaches used in the field of road safety is the accident in-depth investigation (Baker *et al.*, 1960; Moseley *et al.*, 1963; OECD, 1988). The principle of this approach is the detailed analysis of accident cases, based on an elaborate collection of data (see for example Baker and Fricke, 1986), and aimed at understanding the factual sequence of events and causal relations for each case studied. When such studies are based on a conceptual framework and explicit research objectives (OECD, 1984, 1988), they can produce notable results concerning in particular : the *a priori* evaluation of new technical measures, the evaluation of preliminary assumptions or the emergence of new assumptions concerning the production of accidents and the possibilities of prevention. In France, programmes of accident detailed investigations, using such a method, have been implemented since 1980 (Ferrandez *et al.*, 1986; Girard, 1993; Ferrandez *et al.*, 1995), following a more limited programme carried out between 1965 and 1969 (Veil *et al.*, 1970). Although the means used for such studies were often considered to be excessive compared

to the results obtained (Grayson and Hakkert, 1987), they seem, in the past few years, to be the subject of renewed interest, in particular among car manufacturers, and are finding new applications, for example in the *a priori* evaluation of driving aid technologies (Van Elslande and Nachtergaële, 1994, 1993b).

In this type of research, it is especially important to be able to progress from a series of case studies with findings specific to the cases, towards more general conclusions relating to sets of cases (see for example Midtland *et al.*, 1995). In many studies, the general results are expressed in the form of the frequency of involvement of the various causal factors identified (see the review of Saad, 1985). However, taking into account the heterogeneity and the complexity of the phenomena studied, it is useful to keep less disaggregated information, accounting for the bonds between the causal aspects and the sequences of events in which they are at work. Therefore, the need to perform aggregations or classifications of accident case analyses was also felt (see for example: Snyder and Knoblauch, 1971; Saad, 1985). Other research work, not based on in-depth investigations but on case analyses carried out from police reports, are also confronted with this need for aggregation or classification of such analyses (for example: Bernhoft *et al.*, 1989; Bernhoft, 1993; Yerpez, 1996; let us note that, in these studies, the theoretical framework results, in general, from former in-depth investigation programmes). The objective of such classifications is generally to obtain groups of accidents which are homogeneous from the point of view of the phenomena and processes at work, and thus also homogeneous from the point of view of prevention possibilities.

These classifications obviously vary : they can depend on very specific orientations of research (for example the analysis of the functional failures intervening in a precise phase of the accident: Malaterre, 1990; Nachtergaële and Van Elslande, 1994) or deal with a particular aspect of the accident process, corresponding to a narrowly delimited prospect for prevention (for example the supervision of young pedestrians by another person: Wills *et al.*, 1997). In other cases, classifications seem more directly founded on the phenomena, on the accident process, even if the reference to a prevention point of view is ever present (Schofer *et al.*, 1995; Bernhoft, 1993; Snyder and Knoblauch, 1971).

All of these taxonomies are based on accident case analyses, which are carried out by researchers and refer to a general prevention point of view. They thus differ from more conventional typologies derived from the treatment of accident data files usually available.

In some research work, aggregations of case analyses do not have for main objective the constitution of accident classes with precisely delimited boundaries, but rather aim at building and describing accident process prototypes, then constituting a backup for the study of preventive measures (see for example: Fleury *et al.*, 1987; Mercier, 1993; Dansereau and Lupien, 1994; Yerpez, 1996; Brenac and Yerpez, 1997). The cases aggregated around a prototype do not necessarily present a process identical to prototypical process, but there is a more or less large similarity between each one of these cases and the prototype. The accident process concept is not employed in the restrictive sense of a purely factual and dynamic sequence (route, events, manoeuvres, kinematics, collisions, etc.): a prototypical process can also include, for example, certain causal relations, or sometimes certain circumstances regularly noted in the cases studied. In the research work just quoted, these prototypes of accident process are named 'accident scenario' or 'prototypical scenario'. This concept is defined more precisely in the next part of this text, and illustrated

by various examples. In other research work, similar concepts have been used : for example, Bernhoft (1993) describes results concerning sets of accident cases in the form of 'common accident situations'.

Independently of the research work on accident phenomena, generally carried out on specific themes (i.e. dealing with certain categories of accidents), which has just been mentioned, the need for instruments to aggregate or classify accident case analyses has appeared in the field of safety diagnoses methods. By safety diagnosis we mean the safety studies preliminary to the definition of engineering safety measures or local safety policies. These diagnoses must aim at a sufficient understanding of the phenomena, thus making it possible to define appropriate measures. This generally implies the use of relatively detailed analyses of the police reports. This type of study was initially applied to the treatment of 'black spots'. But diagnostic studies are today also applied to wider areas — road section, street, district, and even a whole road network (of a city, for example) — to prepare more general safety measures, or a local safety policy. It is then important to be able to gather accidents which, even if dispersed over a network or road section, present similarities in their process, and can lead to similar preventive measures : these accidents can then be aggregated around a prototypical scenario, as in the research previously quoted. The use of prototypical scenarios in diagnostic studies has been the object of several research (Fleury *et al.*, 1990, 1991; Brenac and Megherbi, 1996; Brenac *et al.*, 1996). The works of Dansereau and Lupien (1994), already referred to above, had other aims, but the authors, however, also insist on their methodological contribution to the safety studies carried out in practical contexts.

2 Concepts and methods

This deals with the accident scenario concept and the relevant methods, as used in the French research.

2.1 The accident scenario concept

An accident scenario can be defined as a prototypical process corresponding to a series of accidents which present overall similarities regarding the chain of facts and causal relationships throughout the various accident stages (see examples figures 1 and 2).

As mentioned above, the term 'process' is used here not only to indicate a purely factual and dynamic sequence (route, events, manoeuvres, kinematic, collision, etc.), even if this is essential. Depending on the case, certain malfunctions (e.g. : failing to notice a motorcycle) or certain causal relationships (e.g. : parked vehicles => hidden young pedestrian), often found in the accidents grouped together, are also included in the prototypical process.

We use the term 'prototype', referring to cognitive psychology, to emphasise the fact that the accident scenario is an abstract construction, illustrating the main features of a series of similar accidents, and not the specific, concrete process of any one of these. As previously stated, the processes of the accidents in this series are not, in general, identical to the prototypical process, but are to some extent similar[1].

Accident cases are usually aggregated on the basis of overall similarities referring to the various stages prior to collision[2]. This means that the similarity is based not only on an aspect of the accident process, for example the manoeuvre performed immediately before the accident, but also on other facts or mechanisms which occurred prior to this (route taken, approach speed, etc.) or subsequently (possible emergency manoeuvre, pattern of impact). This assumes having access to sufficiently detailed analyses of the accident cases in question : for this we use sequential methods of accident analysis which are dealt with briefly in the following paragraph.

2.2 Accident analysis method

Research carried out on accident phenomena, particularly in the context of in-depth investigations, has shown the complexity, dynamic character and the significance of the temporal dimension in accident production. They have led to structure accident analysis by identifying various phases in their process and, more particularly, within the pre-collision stage (Baker, 1960 ; OECD, 1984). More general theoretical considerations on the preventive strategies for injuries and accidents, which show the multiplicity of the possible

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[1] Christoffel et al. (1996) use the term scenario in a different way. For these authors, it is the actual case process, even if the scenario defined for each accident case is then used to form taxonomies, based on the grouping of cases considered to be identical - regarding certain necessarily limited aspects of the accident process.

[2] This principle provides a way of obtaining accident scenarios of which the significance, in terms of prevention, remains sufficiently extensive. In some research, with more limited objectives, this principle is not used, the similarity referring more to a causal or functional sequence leading to a specific event in the accident process (Nachtergaële & Van Elslande, 1994).

levels of preventive action, also lead to the introduction of a temporal segmentation in accident analysis (Andersson & Menckel, 1995 ; Haddon, 1980).

The sequential accident analysis method we have used (Fleury, 1985 ; Ferrandez *et al.*, 1986 ; Brenac, 1997) has been developed for in-depth investigations but has also been adapted to the study of police reports and the context of safety diagnoses. It favours accident prevention and therefore focuses on the pre-crash stage. It is based on a segmentation of the factual accident sequence into various phases :

- the situation prior to driving (should sufficient information be available),
- the driving situation, which describes the conditions and driving activity on the route and the section of route leading to the accident site,
- the accident situation or discontinuity situation : instantaneous, distinguished by an event (e.g. : a manoeuvre at an intersection) or kinematic conditions (e.g. : a high speed on approaching a difficult bend) indicating a shifting over to a critical situation (the emergency situation described below) ;
- the emergency situation, where only extreme manoeuvres could still, in some cases, prevent collision ;
- the collision situation, which includes the collision itself and its consequences

Initially, the various facts or events are situated and described within the various phases. This work of course includes some interpretation, particularly when the data under review (e.g. : police reports) give limited informations.

The investigation is then focused, phase by phase, on the functional processes and the causal factors that have determined these facts or events. This work is based on different theoretical assumptions (e.g. : a model in which the human operator is seen as an information processing system).

2.3 Method used to develop accident scenarios

In most of the French research work mentioned above (Fleury *et al.*, 1987 ; Fleury *et al.*, 1990, 1991 ; Mercier, 1993 ; Brenac & Megherbi, 1996 ; Brenac *et al.*, 1996 ; Yerpez, 1996 ; Brenac & Yerpez, 1997), the method used is an inductive approach, based on an examination of each case, grouping together similar cases and building a prototypical scenario using this case grouping.

The first stage therefore consists of grouping together cases with overall similarities in the accident process. This comparison is both qualitative and holistic : the sequential analysis is not coded (as was the case with Clarke *et al.*, 1995) - there is therefore no formal case comparison -, and the similarity between cases is considered at a general level. There is, of course, a measure of interpretation in this regrouping[3]. A more formal approach

[3] To examine the variability of accident groupings in relation to those who developed them, we asked two students to each develop independently a series of prototypical scenarios using the same sample of 199 accidents representing accidents which occurred in 1995 in a given area of France. To illustrate the regroupings, a co-occurrence table was drawn up, defined by elements aij such as aij = 1, should accidents i and j be related to the same prototypical scenario, and aij = 0, if they are not related to the same prototypical scenario. The two tables of co-occurrence thus obtained, corresponding to the regroupings carried out by the first and second student, were compared using an Euclidean distance, ranging from 0 (perfect similarity) to 1 (perfect dissimilarity). The value obtained in this case was 0.26. Qualitatively, the difference between the series of prototypical scenarios (including 22 and 28 prototypical scenarios) seems to be often linked to differences in depth of detail ; the accidents related to a same scenario in the

would have led to an excessive reduction in the complexity and diversity of the phenomena and would probably only have replaced the interpretative dimension of the qualitative and holistic assessment by an arbitrary choice of coding and weighting of similarity criteria.

When the groupings are in place, it is then possible to build prototypical scenarios. In each group, the comparative examination of the various cases makes it possible to identify the main, most frequent, features of these accidents and to use this basis to construct a prototypical process. The representation of prototypical scenarios can take different forms (purely textual, formal, based on diagrams, combining several forms - Després, 1997 ; Rakotosaona, 1996) and be completed by various elements : information on cases used to construct the prototype, frequency of certain prototypical characteristics, causal factors identified, etc.

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first series of prototypical scenarios were, for example, grouped around two prototypical scenarios which were more detailed in the second series (Delcamp & Pelat, 1996).

3 Examples of the application of accident scenario concept

3.1 Applications for research into certain accident categories.

One of the first French research projects to make explicit use of the accident scenario concept dealt with accidents involving heavy goods vehicles and was based on 33 cases in the in-depth investigation programme at Salon-de-Provence (France) (Fleury *et al.*, 1987). Other research work on other themes (accidents when overtaking, loss of control on bends, etc) have since also used this concept. Among recent research, we can mention Mercier (1993) on traffic accidents in roadwork areas or Yerpez (Yerpez, 1996 ; Yerpez & Girard, 1996) on accidents involving elderly pedestrians in urban areas. In this work, the phenomena-related results are combined as a series of prototypical scenarios, which therefore provide a basis for considerations regarding preventive measures. Mercier, for example, obtained a series of 6 accident scenarios in roadwork areas, and suggested preventive measures in terms of signposting and the organisation of work sites, the management of traffic in these areas and the training of drivers and work-site personnel.

Prototypical scenario n°1 (23 cases)

General conditions and driving situation

In conditions of acute tiredness as a result of work or intensive activity, and/or after a long journey, a driver is travelling along a motorway.

Accident situation (discontinuity)

The driver goes to sleep at the wheel, the vehicle swerves and moves to the left or right, off the carriageway.

Emergency situation

The driver does not react.

Impact situation

Runs into obstacles, ditches, barriers along the side of the carriageway, or turns over.

Main causal factors : acute tiredness linked to a long journey, or linked to working conditions of long distance lorry drivers, or to private activities (e.g. : day spent skiing, etc.) ; lack of sleep linked to long night journey or to working conditions of long-distance lorry drivers.

Main preventive perspectives : checking and regulating working conditions for lorry drivers ; alarm systems (vehicle or infrastructure) to wake up a sleeping driver ; the design of hard shoulders on motorways ; communicating information for long-distance users.

Prototypical scenario n° 2a (7 cases)

General conditions and driving situation

A young, often inexperienced, driver residing locally, is driving along the motorway late at night or early in the morning, often after an evening spent with friends.

Accident situation (discontinuity))

The driver falls half asleep for a moment and his vehicles starts to swerve to the right or to the left.

Emergency situation

The driver jerks the wheel and loses control of his vehicle.

Impact situation

The vehicle usually runs into the protective barriers on the left or, less frequently, on the right of the carriageway, and comes to a halt in the other traffic lane or on the right hand hard shoulder.

Main causal factors : tiredness and lack of sleep due to an evening out or party spent with friends which went on to midnight or beyond ; late time in the night resulting in a need for sleep (circadian rhythm) ; lack of driving experience may lead to an over-abrupt reaction in any emergency situation.

Main preventive perspectives : co-driving or driving control systems in the event of excessive dynamic demands (in an emergency situation) ; driving instruction which includes vehicle behaviour under considerable dynamic demands ; informing young drivers.

Figure 1. Two prototypical accident scenarios on non-urban motorway (adapted from research by Megherbi, 1997)

In recent research into accidents on non-urban motorways (Megherbi, 1997), 290 cases of accidents which occurred on the motorway network in the south of France were analysed using police reports. Twenty six prototypical scenarios were developed. Two of them are summarised in figure 1. They are presented in more detail in the reference quoted.

3.2 Applications for safety studies (diagnoses)

A number of research projects dealing with diagnostic methods have shown the advantages of the prototypical scenario concept in studies used to prepare safety network improvements or local safety policies (Fleury *et al*, ; 1990, 1991 ; Brenac & Megherbi, 1996 ; Brenac *et al.*, 1996). Within such a context, an analysis of unsafety phenomena can be approached from three complementary angles (Fleury *et al.*, 1990, 1991) : the statistical analysis of commonly available accident files, accident cartography and finally a detailed analysis of accident cases using, in general, police reports, with the possible addition of on-site observations. This case analysis approach is essential to understand the phenomena and define action adapted to the local context. The prototypical scenario concept is a way of combining the results of these case analyses. The prototypical scenarios obtained in this manner provide a basis on which to consider the action to be taken, but also concrete backup for the provision of accident information for information campaigns or training.

An example of a prototypical scenario is summarised in figure 2. It is the result of work conducted by Brenac *et al.* (1996). Four hundred and twenty accidents selected at random from the 7200 injury accidents that occurred in the French *département* of the Bouches du Rhône in 1995 were studied. Forty one prototypical scenarios were obtained. This approach forms part of studies conducted in preparation for a road safety plan in this *département*.

Prototypical scenario n° 12a (12 cases)

GC and DS	*AS*	*ES*	*IS*
- Vehicle travelling on urban road. Usually no pedestrian crossing. - Young pedestrian (3-10) usually accompanied.	The young pedestrian, usually hidden by a parked vehicle, runs across the carriageway, his attention often focused on an objective on the other side of the road (6 cases, in 4 of these cases, this objective is the child's mother).	The driver brakes too late. In some cases, he does not have time to react.	The vehicle knocks down the pedestrian

Figure 2. Prototypical accident scenario involving young pedestrian (adapted from Brenac et al., 1996)

This scenario is presented in greater detail, with a list of the causal factors identified for the cases as a whole, in the reference quoted (cf. also : Brenac & Yerpez, 1997). It can be seen that this prototypical scenario may suggest possible measures at several different levels, within the framework of a local safety policy : in terms of general network organisation (e.g., consideration could be given to adapting pedestrian crossings to the needs and usual routes taken by these pedestrians), technical measures (breaking up lines of parked vehicles by extending the sidewalk in places and therefore improving visibility), providing information for both children and parents in schools and associations (paying

particular attention to the behaviour of adults accompanying children). For this type of measure the accident scenario itself provides information that is useful and relatively easy to pass on as it is similar to actual accident phenomena.

4 The development of research into the accident scenario concept.

The concept of an accident scenario, as has just been defined in terms of both the generic characteristics of the accident process and in relation to a prevention-oriented study context, can, if seen from a cognitive science standpoint, be considered as knowledge : a specific accident is not a scenario and a scenario is the result of a combination of information leading to a cognitive construction. This raises several questions that we are unable to deal with here, concerning the status of this knowledge and its relationship to phenomena and action. These questions can be related to research into cognitive psychology regarding mental representations and categorisations (cf., Dubois, 1986, 1991).

We will mention only that accident scenarios can be considered as mental representations that include a certain degree of generalisation and a close relationship with the action. A comparison could be attempted - but with caution - with illness, which could allow us to speak of 'road traffic pathologies'. A metaphor such as this emphasises the logic of the progression of the phenomena (and therefore the mechanisms), the prevention aspect, but also suggests the related concept of symptom, a manifestation linked to malfunctions and which is above all more easily identifiable and possibly measurable. Considered in this way, accident scenarios provide a useful tool for the diagnosis of safety by way of their general nature (synthesis), their constitutive link with preventive action and the possibility of identifying them by way of certain characteristics that could be considered as symptoms.

Other questions can also be examined to envisage using this knowledge within the framework of preventive action :

- what is the consistency and soundness of this knowledge ?
- how can one recognise scenarios already established among significant accident populations for which only limited information is available ?
- what are the conditions for the practical use of this knowledge and, in particular, how can it be integrated into computerised systems for diagnostic purposes ?

4.1 Research into scenario consistency

The usual practice of developing scenarios using an accident sample is a bottom-up type approach which requires checking soundness and generalisation in several ways, by examining :

- the independence of these representations in terms of expert knowledge, in other words, checking that several analysts will construct results that concur;
- the independence of scenarios in terms of the sample of accidents being studied, which consists of checking that they are indeed general 'pathologies' and not specific to a particular site ; to achieve this it is possible to compare the scenarios obtained on similar road networks ;
- finally, the possibility of differentiating the scenarios at different levels ; these descriptions may be very general or very detailed regarding the accident process,

forming therefore a description organised in scenarios and sub-scenarios (knowledge organisation model).

Comparing the results obtained by different specialists

This type of comparison has already been mentioned. To achieve this requires both producing a consensus between specialists and analysing the various frameworks suggested for the construction and representation of accident scenarios. Furthermore, some authors, who do not have extremely reliable information available, are more likely to base their descriptions on the symptoms and contexts within which the accidents occur whereas others, by basing themselves on in-depth investigation data, will focus more on the accident process. Such a formal diversity of results was subsequently used as a basis for *pathology - symptom - environment* relationships to be used in diagnoses.

Contextualisation of accident scenarios

When the independence of scenario construction in terms of specialists has been completed, to be able to speak of 'pathology' requires comparing the scenarios that occur in different types of locations. To achieve this we use two types of approach. The first consists of comparing and combining the results obtained for different populations of accidents that occurred either in urban areas, on country roads or on motorways. Different work already carried out is therefore reviewed to achieve a consensus between the results obtained (Després, 1977). A second approach entails using scenarios constructed from accidents that occurred on the local road network in the Eure et Loir *département* (Fleury *et al.*, 1990) and uses them again as a means of aggregating accidents which occurred on the same type of network in the Bouches du Rhône *département* (Garaud, 1994 ; de Reynies, 1995).

Classifying scenarios

Incorporating scenarios will tend to favour a level of scenario description apparent in previous examples. However, some of this work involves organising the results in groups of scenarios based on the relative similarity of accident processes for certain scenarios or on the similarity of malfunctions with similar origins (Reynier, 1992 ; Rakotosaona, 1996).

4.2 Recognising generic scenarios within an accident population

The mathematical problems involved in the recognition of accident scenarios

It is particularly difficult to compare knowledge obtained from relatively detailed data and data from statistical files which is succinct but which covers a larger number of accidents (Lee & Fell, 1988).

Considerable research work has been aimed at comparing scenarios already constructed to an accident population which, although extensive, comprises information which is superficial in terms of quality and quantity.

The general purpose is to recognise an accident process using descriptive variables that are considered to be more or less representative of certain symptoms[4]. The description of the succession of events in an accident file is, indeed, concise ; on the other hand, other variables may be of good quality. Systematic work to identify the contexts in which

[4] It is this approach that is implicitly followed when inferring a *loss of control* from characteristics of *single vehicle* and *wet road surface*.

accidents often occur, using work already carried out and which involves constructing scenarios, is useful when using these approaches.

In the same way, certain statistical techniques may provide a way of suggesting unrecognised accident groups and so offer specialists a way of constructing new scenarios by referring back to the information contained in the police reports for the corresponding accidents. Different approaches have been tested and have shown the importance of :

- Coding (standard, symbolic) but also weighting (in terms of probabilities or possibilities) representing the frequences of occurrence and also qualitative evaluations of specialists, assessments of the quality of the information, etc.
- The choice of classification methods. A number of solutions are possible and literature on the subject is abundant. Some methods involve case by case approach or a comparison of accident groups and scenarios.
- The similarity thresholds which are tested directly by examining, at different levels, the accident groups likely to be related to a scenario.
- Specialist validation of proposals for new scenarios and a possible scenario classification.

This research work is continued in co-operation with the Universities of Paris V and Paris IX (France).

4.3 Moving towards aid systems using the scenario concept

Accident analysis aid systems

When defining preventive measures likely to improve safety, the data collected by the police is only sufficient up to a certain point. It is sometimes necessary to use an ad hoc collection technique by investigating the scene of the accident either at the same time as the emergency services or later (one or two days after the accident). This type of collection is generally performed by a multi-disciplinary team, as various types of information need to be collected (interviews with those involved, technical data regarding the vehicle, route, etc.) (OECD, 1988). Such work is performed as part of the In-Depth Accident Study in Salon de Provence (France) (Ferrandez *et al.*, 1995).

A research project in collaboration with the Institut National de Recherche en Informatique et Automatique (INRIA) the University Paris V and INRETS (Dieng, 1995) is aimed at obtaining and modelling the knowledge used for accident analysis. Theoretically, road accident analysis requires the use of highly diverse knowledge, and therefore calls upon a number of specialist fields such as mathematics (kinematic), medicine, engineering, psychology, physiology, sociology, etc. Each of these fields provides a contribution that is both specific and complementary and helps to understand the development of such an event within - of course - the limits of the data which is accessible and collected. Collecting this varied expertise requires the use of methods such as KADS which initially provide a means of modelling this analytical work. The following schema suggests an architecture of an accident analysis aid system which should be developed in the years to come.

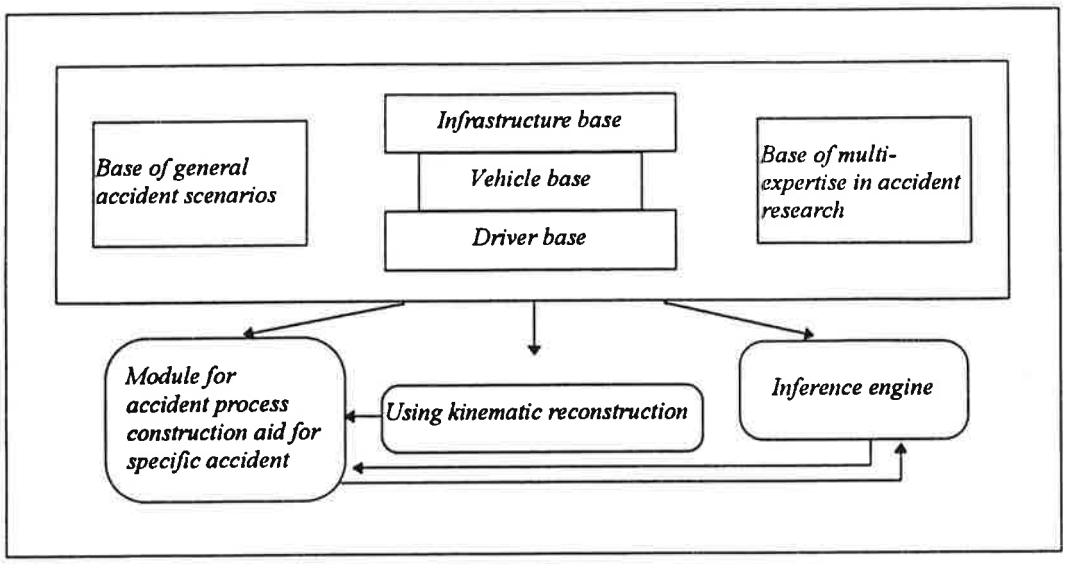


Figure 3. Architecture of road accident analysis aid system (Alpay et al., 1996)

Diagnosis aid system

In a more operational context, the use of the accident scenario concept as 'road traffic pathology' may produce a diagnosis aid to provide addition knowledge linked to the accident processes and relevant action and thus complete the data obtained from police accident files. This is where the metaphor acquires its full meaning as, in this type of file, information on the accident process is generally very sketchy, whereas factual elements can be used to recall specific symptoms. This type of approach continues on from previous work on scenario recognition and has been dealt with in two study projects, one on the design of an operational recognition tool for an existing population of accidents and the other on extending such work to include lexical[5], cartographic and numeric data.

[5] Certain municipal authorities and police services are starting to computerise the texts of accident reports (slightly changed in order to be anonymous).

5 Conclusion

The scenario concept used here is adapted to road safety. There are other applications in the field of research, when designing technical or risk prevention systems. The advantage of this type of analysis was recognised at an early stage - especially in the 70s - particularly with regard to industrial risks when justifying economic decisions made using rational models to weigh up the probability of certain accident scenarios occurring and their consequences in the light of the economic advantages to be gained by a company and the cost of prevention.

In brief, methods are based on experience feedback (accidents or incidents that actually occurred), on simulations that make it possible to calculate the probabilities of failure - including human failure -, or by using expert knowledge, should it be no longer possible to use the previous methods, especially for open-ended socio-technical system applications. In this way the methods can work back from the consequences to the causes (causal tree) or inversely, use graphs to analyse the consequences (failure analysis). This often provides a way of calculating occurrence probabilities. Other methods are based on expertise (interviews with those involved at a local level), analysing complex systems (e.g., a town) to reveal the initiating events, means of protection, means of prevention, severity-increasing phenomena, the consequences, and so construct risk/consequence scenarios to be used to display preventive measures (Theys & Rocker, 1986).

Road accident scenarios, which have been the subject of this paper, are based on the first type of method and constructed using a case by case model of the causal links revealed by analysis to have been at the origin of the accident. It is then possible to consider an a posteriori generic scenario or prototypical scenario (depending on the author) as a construction derived from a combination of several cases considered to be similar.

A completely different interpretation of the term scenario appears in the work of those who collect and reconstruct the accident sequence. This cognitive work refers not only to theoretical models but also to the known and recalled situations that can be identified as permanent scenarios or 'fragments of scenario' and which belong in full to analyst knowledge (Després, 1997). This refers to structures that can be considered to be static (Rakotosaona, 1996) as they previously existed, or dynamic as they recall cases already 'seen' and lead to both classification and analysis. This controversial theoretical question will not be dealt with here as it is discussed in the literature which specialises in cognitive psychology.

It is of course not easy to have direct access to knowledge regarding permanent scenarios. This is why the construction of a system that could be used for accident analysis and to reconstruct the relevant sequence by using a tested and validated a posteriori scenario data base, which will perform the same function as permanent scenarios, is seen as a possible solution for the improvement of analysis (Alpay *et al,* 1996). Such a system assumes prior conditions for the soundness of these a posteriori scenarios in relation to specialist knowledge, inter-road site differences, the mathematical methods used and the similarity tests (thresholds).

To conclude, the development of computer systems based on the scenario concept to assist in accident analysis or diagnostic studies would seem to be an avenue likely to provide

a step forward when considering safety at a local level, and justifies the orientation of our present-day research into road traffic accidents.

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References

Alpay, L., C. Amerge, O. Corby, R. Dieng, A. Giboin, S. Labidi, S. Lapalut, S. Després, F. Ferrandez, D. Fleury, Y. Girard, J.L. Jourdan, D. Lechner, E. Michel, and P. Van Elslande. - *Acquisition et modélisation des connaissances dans le cadre d'une coopération entre plusieurs experts : Application à un système d'aide à l'analyse de l'accident de la route*. Rapport final de recherche. Projet ACACIA (PREDIT/DRAST). INRIA, Sophia-Antipolis, 382p., 1996.

Andersson, R., and E. Menckel - On the prevention of accidents and injuries, a comparative analysis of conceptual frameworks. *Accident Analysis and Prevention*, 27(6), 757-758, 1995.

Baker, J.S. - *Experimental case studies of traffic accidents : a general discussion of procedures and conclusions*. Northwestern University Traffic Institute, Evanston, Illinois, 1960.

Baker, J.S., and L.B. Fricke - *The traffic accident investigation manual. At-scene investigation and technical follow-up*. Northwestern University Traffic Institute, Evanston, Illinois, 1986.

Bernhoft, I.M. - Cyclist fatalities in Denmark. International conference *Strategic highway research program and traffic safety on two continents*, The Hague, The Netherlands, 22-24 sept. 1993.

Bernhoft, I.M., J. Christensen, H.J. Johansen, L. Larsen, and H. Lund - *Fatal accidents involving heavy freight vehicles in 1989*. Report, Danish Council of Road Safety Research, Copenhagen, 1990.

Brenac, T. - *L'analyse séquentielle de l'accident de la route (méthode INRETS), comment la mettre en pratique dans les diagnostics de sécurité routière ?* Rapport INRETS, Outils et Méthodes, n° 3, 79 p., 1997.

Brenac, T., and B. Megherbi - Diagnostic de sécurité routière sur une ville : intérêt de l'analyse fine de procédures d'accidents tirées aléatoirement. *Recherche Transports Sécurité*, n° 52, pp. 59-71, 1996.

Brenac, T., J. Delcamp, S. Pelat, and G. Teisseire - *Scénarios types d'accidents de la circulation dans le département des Bouches du Rhône*. Rapport MA 9611-2, 73 p., 1996.

Brenac, T. and J. Yerpez - Accidents impliquant des piétons : scénarios types obtenus à partir d'analyses fines de cas. *Actes du colloque européen sur les usagers vulnérables dans la circulation, Vulnerabilis 1997*, Lyon, 14-15 Jan. 1997.

Christoffel, K.K., J.L. Schofer *et al.* - Evaluation of a systematic approach for identifying injury scenarios. *Injury Prevention*, 2, 221-227, 1996.

Clarke, D.D., R. Forsyth and R. Wright - *The analysis of pre-accident sequences*. TRL Contractor report, n° 305, 63 p., 1995.

Dansereau, P., and C. Lupien - Scénarios d'accidents et conditions environnementales. *29ème Congrès annuel de l'AQTR*, pp. 65-79, 1994.

Delcamp, J. and S. Pelat - *Diagnostics locaux de sécurité, étude des méthodes d'analyse en scénarios types d'accident*. Ecole Nationale des Travaux Publics de l'Etat, unpublished, 86 p., 1996.

Després, S. - Personal communication (1997).

Dieng, R., A. Giboin, C. Amergé, O. Corby, S. Labidi, S. Lapalut, L. Alpay, S. Després, F. Ferrandez, D. Fleury, Y. Girard, J.L. Jourdan, D. Lechner, E. Michel, and Van Elslande P. - *Acquisition et modélisation des connaissances dans le cadre d'une coopération entre plusieurs experts : Application à un système d'aide à l'analyse de l'accident de la route*. Rapport d'avancement. Projet ACACIA (PREDIT/DRAST). INRIA, Sophia-Antipolis, 62p., 1995.

Dubois, D. - *La compréhension de phrases : représentation sémantique et processus*. Thèse de Doctorat d'Etat. Université de Paris VIII. 1986.

Dubois, D. (ed.) - *Sémantique et Cognition*, Ed. du CNRS, Paris, 1991.

Ferrandez, F., D. Fleury and G. Malaterre - L'étude détaillée d'accidents (EDA), une nouvelle orientation de la recherche en sécurité routière. *Recherche Transports Sécurité*, n° 9-10, pp. 17-20, 1986.

Ferrandez, F. *et al.* - *L'étude détaillée d'accidents orientée vers la sécurité primaire, méthodologie de recueil et de pré-analyse*. Presses de l'Ecole Nationale des Ponts et Chaussées, Paris, 244 p., 1995.

Fleury, D. - L'analyse de l'accident. *Actes de la journée spécialisée Genèse des accidents et perspectives de recherche en sécurité : étude pilote de Salon de Provence*, 1er octobre 1985, INRETS.

Fleury, D., C. Fline and J.F. Peytavin - Les accidents de poids lourds, analyse des dossiers de l'Etude Détaillée d'Accidents. *Recherche Transports Sécurité*, n° 14, pp. 31-39, 1987.

Fleury, D., C. Fline, J.F. Peytavin *et al.* - *Diagnostic de sécurité sur un département, application au cas de l'Eure et Loir*. Rapport INRETS, n° 125, 199 p., 1990.

Fleury, D., C. Fline and J.F. Peytavin - *Diagnostic local de sécurité, outils et méthodes*. INRETS, SETRA, 62 p., 1991.

Garraud, I. - Etude de la robustesse de scénarios d'accidents. Mémoire de DEA (under the supervision of M. Summa) Université Paris IX Dauphine, 1994.

Girard, Y. - In-depth investigation of accidents, the experience of INRETS at Salon de Provence. *ICTCT Congress 1993*, Salzbourg, 27-29 october 1993.

Grayson, G.B., and A.S. Hakkert - Accident analysis and conflict behaviour. In J. Rothengatter et R. de Bruin (Eds), *Road Users and Traffic Safety*, Van Gorcum, Assen, 1987.

Haddon, W. - The basic strategies for reducing damage from hazards of all kinds. *Hazard Prevention*, 16, 8-11, 1980.

Heurdier, S. - Analyse symbolique de scénarios d'accidents. Recherche et interprétation de leur extension à partir de données du BAAC (under the supervision of E. Diday). Université Paris IX Dauphine, 1991.

Lee S.N., and J.C. Fell - *An Historical Review of the National Highway Traffic Safety Administration's Field Accident Investigation Activities*. National Center for Statistics and Analysis - NHTSA Technical Report, Washington, 1988.

Malaterre, G. - Error analysis and in-depth accident studies. *Ergonomics*, 33, 1403-1421, 1990.

Megherbi, B. - *Classifications d'accidents, reconnaissance de l'appartenance d'accidents à des scénarios types : applications aux autoroutes interurbaines*. Rapport intermédiaire MA 9707-1, pour l'ASFA. INRETS, 71 p., 1997.

Mercier, A. - *Les accidents de la circulation au droit des chantiers routiers*. Rapport, INRETS, SPRIR, 80 p., 1993.

Midtland, K., R. Muskaug, F. Sagberg, and N.O. Jorgensen - *Evaluation of the in-depth investigations of the Swedish National Road Administration*. TØI report, 296/1995, Oslo, Norway, 153 p., 1995.

Moseley, A.L. *et al.* - *Research on fatal highway collisions*. Harvard Medical School, 257 p., 1963.

Nachtergaële, C. and P. Van Elslande - *Classification des défaillances des conducteurs selon leur implication fonctionnelle dans la genèse d'un accident*. Rapport, INRETS, 101 p., 1994.

OECD - *Programmes intégrés de sécurité routière*. Paris, 103 p., 1984.

OECD - *Accidents de la route, enquêtes sur le site*. Paris, 113 p., 1988.

Rakotosaona, H. (under the supervision of S. Després and D. Fleury) - *Représentation des scénarios et classifications des accidents de la route*. Université René Descartes, INRETS, unpublished, 1996.

Reynier, A. - Analyse symbolique de scénarios d'accidents. Mémoire de DEA (under the supervision of M. Summa , E. Diday and D. Fleury).Université Paris IX Dauphine, INRETS, 1992.

Reynies (de), A. - Etude méthodologique de la validation de scénarios d'accidents. Rapport de DESS, Université Paris IX Dauphine, 1995.

Saad, F. - L'étude détaillée d'accidents, revue bibliographique. *Actes de la journée spécialisée Genèse des accidents et perspectives de recherche en sécurité : étude pilote de Salon de Provence*, 1rst oct. 1985, INRETS.

Schofer, J.L., K.K. Christoffel, M. Donovan, J.V. Lavigne, R.R. Tanz and K.E. Wills - Child pedestrian injury taxonomy based on visibility and action. *Accident Analysis and Prevention*, 27 (3), 317-333, 1995.

Snyder, M.B. and R.L. Knoblauch - *Pedestrian safety : The identification of precipitating factors and possible countermeasures*. Vol. I. Operations Research Inc. for National Highway Traffic Safety Administration, 1971.

Theys, J., and O. Rocher - Etude de la sécurité d'une ville, Poitiers. In : Colloque international de recherche *Evaluer et maitriser les risques*, Chantilly, 20 - 22 Jan., 1986.

Van Elslande P., and C. Nachtergaële - *Evaluation des CED4 et CED5 de Prometheus : une analyse a priori sur dossiers détaillés d'accidents.* Rapport, INRETS, 1993 (a).

Van Elslande, P. and C. Nachtergaële (1993b) - A qualitative evaluation of RTI demonstrators using in-depth accident analysis and opinion investigation. *ICTCT Congress*, Salzbourg, 27-29 october 1993.

Veil, C. *et al.* - *Etude clinique d'accidents de la circulation routière, rapport final.* Cahiers d'études de l'ONSER, n° 25, 1970.

Wills, K.E., R.R. Tanz, K.K. Christoffel, J.L. Schofer, J.V. Lavigne, M. Donovan and K. Kalangis - Supervision in childhood injury cases : a reliable taxonomy. *Accident Analysis and Prevention*, 29 (1), 133-137, 1997.

Yerpez, J. - Piétons âgés en ville, typologie d'accidents de la circulation routière, le cas de deux villes françaises. *Actes du 3ème colloque national sur la sécurité routière du Maroc "Pour des routes et des rues plus sûres"*, Casablanca, 5-6 dec. 1996.

Yerpez, J. and Y. Girard - *Le piéton âgé en ville moyenne : insécurité subjective et accidents de la circulation.* Rapport INRETS-PIRVilles, 115 p., 1996.

2. BEHAVIOUR ANALYSIS

Chairperson: Risto Kulmala

• **The "Older Driver Problem" – myths and facts.** HAKAMIES-BLOMQVIST Liisa, VTI, Linköping, Sweden

• **Traffic experience and problems of elderly pedestrians in urban traffic**. PAPP Irén, PAPP Miklòs, OCTAV, Budapest, Hungary

• **Children's understanding of other road users' behaviour.** OGAWA Kazuhisa, Faculty of Human Sciences, Osaka University, Japan. PAPP Irén, OCTAV, Budapest, Hungary

• **Young children's safety understanding and behaviour in traffic situations.** BRIEM Waldimar, BENGTSSON Hans, Dept of Psychology, Lund University, Sweden

• **Observation of crossing behaviour in the vicinity of pedestrians subways.** SISKA Tamás, OCTAV, Budapest, Hungary

• **Search Strategies in Simulated Traffical Situations Investigated with a Stationary Eyemarker Equipment.** HETMAR Gorm, Consult.us, Copenhagen, Denmark

• **Effects of variable road condition signs on reported driver behaviour.** LUOMA Juha, RÄMÄ Pirkko, PENTTINEN Merja, HARJULA, Virpi, VTT, Finland

• **A Driving Simulator Test of an Alertness Device.** VERWEY Willem B, ZAIDEL David M, TNO, Human Factors Research Institute, the Netherlands

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The "Older Driver Problem" - myths and facts

The "older driver problem" is considered as the result of the increasing number of older drivers in the traffic system, and their higher than average accident risk. When accident risk is estimated on the basis of the equation Risk = Accidents / Exposure, there are possible sources of error in both the numerator and the denominator.

Numerator. Depending on the nature of the database, older drivers' accidents may be overrepresented because of the aging organism's greater physical frailty. Generally speaking, the more the inclusion of an accident in the database is dependent on the seriousness of the outcome, the more overestimated will any calculated increase in age related risk be.

Denominator. If risk is understood as expected societal costs caused by a given age group, accidents per population is an adequate measure. If the number of driver licenses is used as exposure measure (as a reasonable estimate of the number of active drivers), the necessary conditions for license holding should not differ between the different groups under comparison, since any legal obligations connected to a driver group's maintaining a valid license will affect the group's active drivers/licensed drivers ratio. The more restrictions there are for a given group's license holding, the fewer licenses they will hold, and the higher risk estimates will result. When mileage driven is used as a "hard" exposure estimate, older drivers' risk will be overestimated, since they drive less, and low mileage drivers have, independently of age, higher accident rates than high mileage drivers. In risk calculations based on induced exposure, cautious driver groups like older drivers, with defensive driving style and generally lower speeds, will get inflated risk estimates, since they manage to avoid being hit as innocent parties. The magnitude of the error will vary depending on how the sample of accidents is limited as to place, time, or accident type. Since findings from experiments in cognitive gerontology consequently show an age related increase in interindividual variance among healthy older subjects, variance in accident risk, accentuated by illness related performance deficiencies, must be even higher. The distribution older drivers' individual accident risk may indeed be bimodal rather than normal; in virtue of their cautious driving style and self critical attitude, many older persons are extremely safe drivers, while certain pathological subgroups will have functional decrements leading to considerable risk increase.

Traffic experience and problems of elderly pedestrians in urban traffic

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Abstract

The mobility and well-being of elderly people is clearly connected with their ability to cope with different traffic situations. Although there is general agreement that senior pedestrians should be protected on the road, their real needs seem to be often neglected. One reason for this may be an oversimplification of the safety targets, in which the spotlight tends to be directed rather on the young road users than on elderly traffic participants. Another explanation may be the lack of detailed knowledge about the everyday problems encountered by this road user group in urban traffic.

An analysis of these problems was made 1. by a questionnaire survey (n=335) assessing some attitudinal aspects as well as physical difficulties of traffic participation;.identifying some disturbing elements in the traffic environment; and problems in interactions with younger road users and drivers 2. by observing the behaviour of elderly people crossing the road on three signalised crossings (n=405).

Based on accident data and the above mentioned studies, further research needs were outlined. and ways to improve the quality of life of elderly pedestrians were recommended.

1 Safety situation of elderly pedestrians

Every fourth pedestrian accident in Hungary and every third in Budapest occurs to pedestrians over 60 years of age. As far as accident severity is concerned: according to a detailed analysis carried out for the year 1993, approximately 40% of the fatal pedestrian accidents in Hungary occurred to people over 60. The analysis of the data recorded on the accident registration forms shows that

- one third of the accidents occurring to elderly pedestrians in built-up areas happens on pedestrian crosswalks,
- a smaller proportion of the elderly pedestrians can be blamed for their accidents than of pedestrians belonging to other age groups (while 48% of the total number of pedestrian accidents is caused by the pedestrians themselves, this value is only 38% in the case of people over 60 years of age),
- the injuries of the elderly are more severe: while the accidents occurring to 7-14 year olds e.g. have a fatal outcome in 3% of the cases, this number is 18% for pedestrians over 60 years of age.

Using the terms of the accident registration form, we analysed pedestrian behaviour leading to a personal injury accident (N=416). These are:

Inattentively, abruptly stepping into the roadway (46%)
Crossing where prohibited (14%)
Crossing where visibility is obstructed (13%)
Crossing against red signal (11%)
Disturbing behaviour while crossing (10%)
Other (6%)

The major accident causes attributed to the pedestrian (38%) clearly show the deficiencies in the performance of the elderly, which may be due to deteriorating abilities, or sometimes also to not knowing the rules, not having experience as drivers etc. It is relatively rare that the elderly cause risky situations by intentionally violating the law. The statistical data are often misleading, because they state the „faulty" behaviour of the elderly pedestrians also in such cases, when they are simply not able to cope with a given traffic situation.

The majority of pedestrian accidents analysed (62%) was attributed to driver errors. Drivers endanger the elderly mainly by selecting inappropriate speeds, by breaking the priority rules, not giving priority to them and by being negligent. Further accident causes are illegal overtaking, illegal turning and reversing. Some further characteristics are:

- 8% of the elderly pedestrians causing their own accidents were under the influence of alcohol;
- 6% of the drivers hitting elderly pedestrians were under the influence of alcohol;

- the age of the majority of drivers causing pedestrian accidents under the influence was between 18 and 43 years.

It seems that the elderly are given the right of way at pedestrian crossings less often than are younger pedestrians. This observation would require and deserve further research.

2 Difficulties in urban traffic: a questionnaire survey

2.1 Method and objectives

In a questionnaire survey in 1994 we tried to reveal the general feelings of the elderly in urban traffic and the difficulties experienced by them as pedestrians. We wanted to gain insight into their attitudes to safety, as well as into the acceptance by them of different accident countermeasures.

The questionnaire was completed by 335 persons: 130 men (39%) and 205 women (61%). The average age of the respondents was 69,7 years. The questionnaires contained 23 groups of questions, and were completed by the elderly themselves, assisted partly by family doctors and partly by trained interviewers. Before the elaboration of the questionnaire, interviews were conducted with elderly pedestrians in downtown Budapest. The analysis of these and of written comments voluntarily added to the questionnaires are discussed below.

2.2 Discussion

The circumstances (inconvenience or comfort) experienced on the road by elderly people seem to have a decisive influence on their mobility. If they often have to face situations with which they find it difficult to cope, they will more and more avoid participation in traffic. (This was confirmed by the above mentioned series of interviews.) One should not forget that this 'automatic' decrease in mobility deteriorates the quality of life of the elderly at the same time.

Fundamentally, the elderly seem to be very tolerant towards drivers, young people and also towards the difficulties they have to face in traffic. Most of them are satisfied with what they are still able to do in terms of traffic participation, even if many of them voluntarily restrict their mobility.

Based on their experiences, some of the respondents are inclined to generalise their negative judgements with regard to young people. They mention examples which show the intolerance of many young drivers towards the elderly and even their rude behaviour and lack of empathy. The impoliteness and rude manners of young people is hurting the elderly in many cases, particularly if it takes the form of verbal abuse.

33% of the respondents have fears that they won't be able to cross the road during the green phase of the traffic signal. A higher proportion of women have those fears than men. More than a quarter of the respondents had been involved in an accident or serious conflict before. If we analyse the fears according to this, we see the following picture. In the non-accident group the women are anxious because of the short green phase twice as often as are the men (39%/20%). While women have these fears

independently of whether they are accident-free or not (39%/39%), the accident history seems to be decisive in the case of men. 20% of the men belonging to the non-accident group and 30% of the men in the accident-group have fears of not being able to complete the crossing on green signal.

The vehicles parked on the pavement cause further difficulties, especially when the pedestrians need to use the roadway because of them. The elderly would like to retain the pavement for the pedestrians. Cyclists, skateboard riders, roller skaters on the pavement are felt to be threatening by them.

Every fifth respondent objects that the kerbs are not well visible, not painted. Some of the elderly have problems with using the escalators. Slippery roads are perceived to be extraordinarily dangerous. The elderly would like to see more benches in the streets, enabling them to have a rest during their trips.

Half of the respondents think that the police enforcement is not strict enough. They stress that traffic education should begin in early childhood and express their opinion that the education for considerate behaviour seems to be missing nowadays.

The attitude of the elderly towards speed is different from that of younger people, as so is their relationship to 'time'. They don't always understand the haste and hurry, which they are well able to associate with 'risk'. Interestingly, some of them are worried not only about their own safety, but about the drivers, who endanger themselves by selecting high speeds or getting in trouble when hitting an (old) pedestrian.

Many elderly pedestrians report to have difficulties while crossing the road at signalised crossings. Some of them expressed: they would welcome if additional acoustic signals would help them and others with visual impairment in crossing the road more comfortably and safely.

It seems justified to say that the quality of the relationship and of the communication going on between the young and the old, as well as the quality of the road environment itself are key factors in the safety and well-being of elderly pedestrians.

For the elderly or handicapped people the quality of the road and its environment is extremely important. It would be of much value for them, if the difficulties inherent in the environment and sometimes due to the behaviour of other road users could be eliminated. They try to compensate for their deficiencies by devoting more time to traffic participation and/or avoiding this in darkness, in rush hours etc.

The majority of the elderly seem trying to do their best by compensating for their deficiencies, by being overcautious, keeping to the rules etc., but they simply fail because of the limits of their physical abilities. The responsibility - of traffic experts in general and of other traffic participants on the road in particular - to help overcome these difficulties is great.

3 Behaviour at signalised crossings: an observation study

3.1 Method and objectives

It is a well established fact that the elderly are at an increased risk in traffic. The high number of their accidents on pedestrian crossings is an indication for their handicaps even in „protected" situations.

An observation study of the behaviour of elderly pedestrians (n=405) at three signalised crossings in Budapest was carried out, during three hours of observation time on each site. The subjects were elderly pedestrians beginning to cross the road with the green phase of the signal. Intentionally violent behaviour (e.g. beginning to cross on red) has been excluded from our study. We wanted to gain insight into the difficulties experienced by this group of pedestrians in situations which are thought to be relatively the safest. We concentrated on the characteristics connected with the age factor, determining to some extent the pace of movements and the circumstances of traffic participation.

Using an observation sheet, we focused our attention on the pace of movement, on eventual handicaps (including heavy bags) and on the characteristics of behaviour before, and during the crossing. Based on the behaviour, facial changes, movements and gestures, --- where it was possible -- we also recorded our impressions of the observed persons' general feelings in traffic.

The following items were recorded: pattern of accompaniment, apparent difficulties because of some „extra load", making it difficult to move (or indicating handicaps), attention paid to traffic (or the lack of it), pace of movement and whether the pedestrian was able to reach the opposite kerb on green (or flashing green) signal or on red. Only the pedestrians starting to cross with green or flashing green were dealt with.

We recorded the accompaniment patterns (if the pedestrian was taking part in traffic alone, with a contemporary, accompanying a child or accompanied by someone assisting him).

The characteristics of interactions between drivers and pedestrians could not be observed, because in the investigated situation there were no interactions at all, except for some 'almost critical' situations.

3.2 Discussion

74% of the observed elderly were walking alone, 23% were in the company of contemporaries. Assistance in walking was needed by 2%, and only 1% were taking part in traffic with a child.

93% of the persons observed were starting to cross on green signal, and 7% on flashing green. 57% of them were walking at a normal space. 20% were walking slowly and 23% had apparent handicaps. Only 15% of the observed pedestrians were able to complete their crossing on green or flashing green, 85% had to do so on red signal.

The differences between elderly men and women with regard to visual attention and crossing behaviour have been analysed. Elderly men were found to be less uncertain during the crossing, and showing less apparent fear reactions and handicaps of movement (26%/17%)..

In our sample, men were more often accompanied by contemporaries, than women (26%/20%). A somewhat higher ratio of women were characterised by moving slowly (23%/17%).

There was a considerable difference in the pattern of attention paid to traffic: while 44% of men looked to the left before beginning to cross the road, this number was only 31% for women.

28% of the men and 38% of the women did not pay any attention to traffic while crossing.
13% of the women and 17% of the men were able to complete their crossing on green signal. Consequently, 87% of the women and 83% of the men were „forced" to complete their crossing on red.

There are some apparent signs of difficulties experienced by the elderly pedestrians, indicated by:

- very slow movement, physical handicap,
- the use of a walking stick,
- carrying heavy bags or using shopping carts.

A consequence of the stress they are exposed to may be illogical, irrational behaviour (e.g. running over the road unexpectedly, or crossing diagonally.)

The apparent lack of attention is characteristic for many of the elderly pedestrians, the causes of which may be of mental, physical or 'social' origin, or the combination of these, e.g.:

1. The pedestrian is involved in some activity while crossing (conversation, having an ice-cream etc.)
2. Walking itself requires the full attention of the pedestrian. He/she focuses on how to keep on proceeding and not falling over and no capacity of his/her attention remains

free for observing traffic. In such cases the bad condition of the pavement means extra difficulties.

3. In those cases when two elderly pedestrians are walking together, one of them is usually leading the other, trying to pay attention to traffic. The problem of slowness is there also in such cases, even if some attention will be devoted to the vehicles.

Further characteristics are:

- cutting the way, trying to shorten it according to the direction of destination,
- going about dreamily, sleep walking,
- walking with head hung down,
- looking in the wrong direction (opposite to traffic),
- looking in both directions several times one after the other,
- apparent effort to hurry up when the signal turns red,
- emergence of risky situations because of slow pedestrians on the road.

In the „safe" situations investigated, signs of scare, getting frightened of engine-notes were observed in a number of cases. These negative feelings may partly explain the irrational actions, as running over the road, or the repeated ritual trials of orientation. The inconvenience felt by the elderly could be detected from the movements and facial expressions of the persons observed, similarly to the apparent release experienced when reaching the other side of the road.

In the crossing situation which has been selected for the survey, it was practically unnecessary that the pedestrians establish communication with the drivers. This would have been difficult or even impossible in most cases, because of the difficulties of the pedestrians. It is not known, whether using a signalised crossing is a conscious decision on the part of the elderly, by which they are trying to diminish he risk of crossing. Most probably it is, as in another investigation it became clear that when getting on a bus, the elderly tended to choose the door nearest to the bus driver for their safety. ...% report on this behaviour.

4 Conclusions

The most important findings of the surveys are as follows:
- about half of the pedestrians are moving slowly and have some mobility handicaps (heavy shopping, using walking sticks, pulling shopping carts etc.);
- the majority of them are trying to compensate for their deficiencies and to cope with traffic;
- the signalised crossings don't offer sufficient protection for the elderly; often they don't make an anxiety-free, comfortable crossing possible for them
- the elderly make errors in the investigated situations, the causes of which may be the deficiencies due to the normal ageing process, a lack of attention or knowledge, or the intention to shorten the length of way;
- their traffic participation and well-being (general feelings) are apparently deteriorated by traffic related pressures, such as being forced to act under time pressure and this can be seen from their movements, facial expression and behaviour;
- the bad condition of the crosswalk itself may cause further problems, generating fears of falling down;
- the accumulation of negative experiences in traffic may lead to a gradual narrowing of the mobility of the elderly, the consequences of which will appear as problems to be solved in health care and other forms of social care about the elderly.

The results of the observational study allow us to conclude on the difficulties of the group in question in other crossing situations as well. As it is clear from accident statistics, the crossings without pedestrian facilities are not less critical sites with regard to the safety of the elderly. At these sites, there is no feeling of safety given by the signal: communication with the driver and an overview of the situation is needed. This is – similarly to the observed difficulties on signalised crossings - a task difficult to cope with for pedestrians moving at a slow pace or having other handicaps.

The investigations have confirmed our assumption that the elderly are in a disadvantaged position even in the 'best protected' crossing situations. The improvement of their safety can be reached first of all by the modification of environmental conditions, an important element of which are: timing of signals better adjusted to the needs of the elderly, acoustical signals, better lighting conditions after dark as well as the better quality of the road surface, especially of the crosswalks. As the elderly are not always able to identify hazards, another approach might be the introduction of risk perception exercises already used in some countries. A part of the elderly who are still open to take part in group activities may benefit from these. The application of intensive techniques of mass communications to influence the behaviour of the elderly pedestrians seems equally important. Younger road users should be made aware of the typical reaction patterns of the elderly, their problems experienced on the road and of their increased risk of severe injuries. Safety publicity efforts should focus on improving the relationship between the young and the old, aiming at a better communication between these two groups in general and on the road, too.

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LITERATURE

1. Chaloupka, Ch.; Fous, R.; Risser, R.; Lehner, U.: Erhöhung der Sicherheit der Seniorinnen und Senioren im Strassenverkehr. Wien, 1993.

2. Evans, A.V.: Transport Accidents and Other Accidents. Older Road Users. The Role of Government and the Professions. Proceedings of a one-day conference held at the Royal Society of Arts, 19 November 1993, London.

3. Nagayama, Y.: Traffic Accidents and the Elderly in Japan. Wheel Extended, 1992/03.

4. Papp I.: Idös gyalogosok biztonságának javítása (Safety improvement of elderly pedestrians). KTI/OCTAV, Budapest, 1994.37 p. (Konzulens:dr. Holló Péter)

5. Papp I.: Idős gyalogosok átkelési magatartásának helyszíni vizsgálata jelzőlámpás gyalogátkelőhelyeken (Crossing behaviour of elderly pedestrians on signalised crossings) Budapest, 1995. 25p. (Konzulens: dr Holló Péter)

6. Draskóczy, M.; Hydén, Ch.: Pedestrian Safety Measures - Past and Future. Lund, 1994.

7. Wilde, G.J.S.: Mass Media Communications for Pedestrian Safety. Kingston, Ontario, Canada, 1976.

8. The SKANDIA Report III. Unprotected Road Users. A behavioural study by Stina Sandels. Stockholm, 1979.

9. Elderly Road Users - A Synthesis, June 1987. U.S. Dept. of Transportation.

10. Schlag, B.: Europaischer Kongress zur Verkehrssicherheit alterer Menschen. Zeitschrift für Verkehrssicherheit 40 (1994) 2 .

11. Mütze, M.; Rehberg, H.: Der altere Mensch im Strassenverkehr. Forschungshefte zur Verkehrssicherheit, Heft 14, 1984. Hochschule für Verkehrswesen 'Friedrich List', Dresden

12. Van-Schlangen, I.; Maring, W.: Problem analysis of Older Traffic Participants. Rijksuniversiteit Groningen, 1992 (VK 91-09).

13. Gunnarsson, S.O.: The Problems of the Pedestrians. Conferenza Internazionale Vivere e Camminare in Citta....Urbano. 1994/06.

14. Papp I.: Az idős gyalogosok tapasztalatai és problémái a városi közlekedésben (Experiences and problems of elderly pedestrians in urban traffic). KTI/OCTAV, Budapest, 1994. 34 p. (Konzulens: dr. Holló Péter. Közreműködött: Papp Miklós.)

CHILDREN'S UNDERSTANDING OF OTHER ROAD USERS' BEHAVIOR

Ogawa,K. Papp,I.

1 Introduction

The aim of this study is to reveal what children see in the road and what they think of road traffic. Children participate in traffic as pedestrians or cyclists in everyday life. They have already obtained various kinds of knowledge and experience about road traffic besides what they learn in traffic education at school. However, few studies have ever tried to focus on how road traffic is reflected in children's eyes.

Most Japanese children have only two classes for traffic safety during 6 years of primary school. In most cases, they learn basic traffic rules and basic safety behavior, e.g., how to cross the road, how to ride a bicycle. It is while they attend driving school that they obtain knowledge about traffic safety again. There are few opportunities for children to learn about traffic safety if we consider that they are exposed to accident risks in everyday life. It is desired in Japan to establish traffic educational programs which provide children with more knowledge and skills for accident prevention. For this purpose, it is important to examine what children understand about road traffic and what they don't understand.

Two types of survey were conducted in order to discover what children recognize in traffic environment. One was to ask children to draw what they see in traffic situations. The other was to ask children to express what they think of traffic problems. The findings could contribute to the development of traffic educational programs.

2 Methods

2.1 Survey 1 : Drawing traffic situations

The sample consists of 53 boys and 57 girls. They were all 3rd-graders (8-9 years old) at a primary school in Osaka, Japan. Children were asked to draw traffic scenes they see daily on their way to/from school or their friends' houses. They were instructed to draw the traffic scenes with color pencils on white drawing paper within 45 minutes.

2.2 Survey 2 : Expressing opinions about traffic problems

55 boys and 64 girls (10-11 years old) were asked to write their own opinions or essays about traffic problems. They were all 5th-graders at the same school as the above-mentioned 3rd-graders. In order to help them express their opinions, four questions were listed on the answer sheet in advance. The questions were as follows;

Question 1 : What do you think of cars you see in the road ?
Question 2 : What do you think of adult pedestrians and adult cyclists you see in the road ?
Question 3 : Why are a lot of people involved in traffic accidents ?
Question 4 : Imagine that you are a police officer for one day. What do you see in the road ?

Children were told to choose two of the questions and write freely what they think. They were also asked to write down their opinions on the answer sheet by pencil within 45 minutes.

3 Results

3.1 Results of drawing traffic situations

The method used in this study is the same method that Papp & Ogawa (1990) used. They found that Japanese children drew fewer drivers in the cars than Hungarian children did. One possible explanation is that Japanese children don't care about interpersonal communication, i.e., eye contact, with drivers much. In the present sample, it was again found that many children drew pictures of cars without a driver's face.

In addition, there were drawings which indicate that children are surrounded by dangerous and uncomfortable traffic environments. Some children drew cars running at high speed. Others drew many cars in the narrow road near their houses. There was a girl who expressed uncomfortable feelings at the sounds made by ambulances and police patrol cars.

3.2 Results of expressing opinions about traffic problems

Many children answered the question concerning the causes of traffic accidents. 95 of 119 children (79.8%) selected Question 3. It follows from this result that children are greatly interested in traffic accidents. The number of children who selected the remaining

questions is 62 children for Question 1 (52.1%), 38 children for Question 2 (31.9%), and 41 children for Question 4 (34.5%), respectively. The following are some samples of children's opinions ;

Question 1 : What do you think of cars you see in the road ?

- I think that there are a lot of people who don't wear seat-belts... When there is no policeman standing, drivers don't wear seat-belts. But when drivers find a policeman, they scramble to put on seat-belts. It is better to wear seat-belts from the beginning, I think. (11 yr.-old girl)
- As cars run at too high a speed, and are parked in the no-parking areas, we must walk carefully...I can't go ahead, because cars are parked in the narrow road. I can't sleep well at night because of noise from cars. (10 yr.-old girl)
- Adults driving cars sometimes disregard traffic lights. I wonder what they would do if they hit a person ? (11 yr.-old girl)

Question 2 : What do you think of adult pedestrians and adult cyclists you see in the road ?

- When I saw a high school student riding a bicycle at a surprisingly high speed and disregarding the red light, I thought it wrong...I saw young adults not obeying traffic signals and rules... (11 yr.-old boy)
- I sometimes think something wrong. The reasons are that when I was waiting at a traffic signal, an adult cyclist crossed against a red light, and that I saw an adult pedestrian crossing even if a green light started blinking... (11 yr.-old girl)
- Even at night, adults and young people ride bicycles with the lights turned off. So, I can't see their bicycles and I am likely to collide with them... (11 yr.-old girl)

Question 3 : Why are a lot of people involved in traffic accidents ?

- When I glanced at cars, I many times found drivers who grasped the wheel one-handed, drivers who were looking this way and that, and drivers who ate and drank something. So, traffic accidents happen and sorrowing people increase, I think. (10 yr.-old girl)
- They drive playfully. They drive with a portable phone, when they drop it at their feet and try to pick it up, accidents happen... (11 yr.-old girl)
- ... Behind the parked car, we don't see whether a car is approaching or not. But we think ,"Well, it may be all right." And then we cross and collide with a car...(10 yr.-old girl)
- There are people who disregard traffic lights, violate speed limits, drink and drive... (10

yr.-old boy)

Question 4 : Imagine that you are a police officer for one day. What do you see in the road ?

- I think that I can see a lot of accidents... I think that there are people who hit and run. I don't want to see such an accident even for one day... (11 yr.-old girl)
- I want to caution persons who don't obey the traffic rules...I want to guide young children who don't understand the traffic rules. (11 yr.-old boy)
- I think that I see people who drive in a risky way, ...people who drive while holding a baby... (10 yr.-old boy)
- I see whether drivers are wearing seat-belts or not, whether children are playing at the construction site or not, ..., and whether people with a stick are walking at a long pedestrian crossing or not. (10 yr.-old boy)

We can summarize their essays and opinions as follows : Firstly, children see other road users' behavior with a critical eye, especially, adults' behavior, which seems illegal, risky, and irresponsible to children. Secondly, children have much knowledge about the kind of behavior that could lead to accidents. Many children thought that driver behavior against traffic rules could be an important factor of accidents, e.g., disregarding traffic lights, drinking and driving, running at a high speed. There were also children who pointed out careless behavior of road users, e.g., crossing without looking, believing that no cars would come before crossing, driving while watching TV, driving while holding a baby. Furthermore, some children tried to describe the process of human error in a concrete way, e.g., how drivers make driving errors while using a mobile phone.

4 Conclusion

What can we learn from these data ? The sample of 10-11 year- old children suggests that children have the ability to observe the traffic behavior of other road users with an objective eye. They have already obtained much general knowledge about dangerous situations, risky behavior, and basic factors of traffic accidents from their parents, mass media, and their own experience. The important thing is to produce well-planned educational programs so that children can obtain more concrete information which can be utilized in real traffic situations, for example, showing children a map which indicates

dangerous intersections and roads in the neighborhoods of their houses and school.

The results also show the possibility of changing adults' attitude. As mentioned before, many children pointed out that adults' behavior is risky and illegal. If these findings are shown to parents and other people in the community through the Parent-Teacher Association or other local community networks, it could raise their awareness of traffic safety.

References

Papp,I.& Ogawa,K. 1990 Comparison of Hungarian and Japanese children's view of road traffic, based on drawings. 22nd International Congress of Applied Psychology, July 22-27, in Kyoto, Japan.

Young children's safety understanding and behaviour in traffic situations.

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Abstract: 45 children (3:6-6:9) were observed in 2 traffic situations, (a) a traffic model, where they used dolls to enact the movements of two children on the way to and from day-care, and (b) as they crossed a lightly trafficked, minor road in a situation analogous to that in the model. Special attention was given to road-crossing behaviour, seen here as a task consisting of 3 components, (i) using a zebra crossing, (ii) stopping at the curb, and (iii) looking for cars. The results showed that the children's performance on the 3 components was differentially related to their safety knowledge and understanding. Age and understanding were shown to be important predictors of the ability behave appropriately in both traffic situations. In the model, correct behaviour was shown more often in the use of the zebra crossing than in stopping and looking for cars, while the opposite was true for the roadside situation.

1 Introduction

Available research concerning the ways in which young children cope with risky situations encountered in traffic is at the present time fairly limited. We lack, for instance, concrete information about the relation between children's knowledge and ability to reason correctly about the traffic and their behaviour in traffic environments (cf. Vinjé, 1981), the ways in which children conceptualise risky situations, and how their concepts of risk and safety influence their behaviour. All in all, the role played by cognitive factors in young children's ability to cope with dangerous environments, such as the traffic, is still a relatively under-researched area.

The conclusion of most studies of young children's contact with traffic is that they cannot be expected to be able to cope with the complex situations and decisions encountered in this environment (Rothengatter, 1981; van der Molen, 1981; Vinje, 1981; Phinney, Colker, & Cosgrove, 1985; Briem, 1988; Ampofo-Boateng & Thomson, 1991). Some putatively causal factors highlighted here are cognitive in nature, such as e.g. the children's attention, judgements of safety and risk, and perception of relevant spatial and situational attributes. Results from the available studies of these factors indicate that, compared with older children and adults, young children have relatively little control over their attention and momentary impulses, are less adept at localising sound, have a narrower visual field, as well as a difficulty attending to several aspects of the traffic situation at the same time, and are poor judges of the speed of oncoming vehicles (Sandels, 1970; Salvatore, 1973; Pfeffer & Barnecutt, 1996). We can conclude that, because of these cognitive limitations, young children are at considerable risk in many traffic situations.

Kail (1990) has proposed that the development during childhood of several, important, cognitive functions mirrors the development of an underlying information processing

mechanism. In support of this hypothesis, Kail provided material from a number of his own studies, which demonstrates that the processing time in a variety of cognitive tasks, given to groups of children of different ages, decreases as a function of the children's age. This indicates that young children's attention and memory capacity is fairly limited, and only begins to approach adult level in the early teens. One effect of this might be that young children are only able to deal effectively with a single or a limited number of aspects of any given situation at a time. In a dangerous environment, such as traffic, where quick decisions have to be made between several important possibilities in the situation and tasks to be performed, a wrong decision may have serious, or even fatal, consequences.

Some of the behaviour that takes place in traffic situations may be characterised as the following of some rule or other, but these are usually taken for granted, and only a few of them are explicitly defined, such as, e.g., the *"Green Cross Code"*. The development of these rules may be taken to be analogous to that of any other rules. Siegler (1978, 1981) studied the way young children use rules when solving problems, and proposed that children do not begin to develop a rule-governed approach to problem solving until about the age of five. To begin with, the rules used are simple, but are replaced later on in the children's development by sophisticated rules that take into account more complex aspects of the problem situation (cf. also Case, Marini et al., 1986; Zelago & Shultz, 1989). There is no reason why we should not expect to find a similar development in children's ability to follow rules in traffic. This increased ability would most likely also entail a more general understanding of risk and safety.

It may seem reasonable to suppose that a child who *knows* that it is dangerous to step into the road in front of an oncoming car is less liable to do so than a child that does not know this. Ryle (1949) proposed that there are two distinct kinds of knowledge that a person may possess, and he referred to these as *Knowing How* and *Knowing That*. In psychology, these are sometimes referred to as *Procedural* and *Factual knowledge*, respectively. This does not refer to the difference between knowing facts, such as *cars are made of metal* or *the road is 10 meters wide*, and knowing how to describe procedures (or *rules* or *scripts*), such as *when you cross the road you must stop, look left, right and left again, and cross if all is clear*. The difference is between knowing facts and rules, explicitly formulated in words, and knowledge that is shown in action, referred to as *"skills"* (Ryle, p. 30). A young child may possess many different items of knowledge, relevant to safety in a traffic situation. This knowledge would be both factual, like knowing that such and such a thing *is* a reflector, and procedural, like knowing that you must pin a reflector onto your coat when it is dark, and skills, like riding a bicycle or pinning the reflector on before going out.

But the child may or may not be able to associate these different kinds of knowledge to each other in a real traffic situation. The child may know a certain thing to be a car and this thing to be "dangerous", but may not be able to place it conceptually in the class of things adults refer to as "vehicles". Then, standing at the side of the road, and seeing some unknown vehicle coming along the road, the child may not realise that this thing is equally dangerous as a "car". Also, the child may know exactly what its mother said about it being dangerous to walk across if there were cars nearby, that the child should stop at the curb, and look carefully before crossing. The child, following the mother's instructions carefully, stops at the curb, waits, looks around, left, right, left again, and then confidently steps into the road, in front of the oncoming vehicle (cf. Sandels, 1974).

What is lacking in situations such as these that makes the knowledgeable young child so vulnerable? The child knows about the danger, and follows the procedures laid down for crossing, but is still at risk. The young child may, in fact, possess any amount of items of both factual and procedural knowledge, as well as the appropriate skills, but still not be able to apply them properly when they are really needed. What seems to be missing is a *proper understanding* of what a dangerous situation involves.

The definition of "understanding" offered here is stricly operational. It refers to the *ability*, given the possession of the relevant factual information and skills, to perform an appropriate action when needed. A "proper understanding" in the present context then refers to a child's ability to avoid dangers encountered in traffic, as a consequence of possessing the relevant knowledge, as well as being able to apply it appropriately and explain it satisfactorily when needed. Then it is essential for the young child both to know (i) what are *risky situations*, (ii) what the possible *actions* in such situations are, (iii) to have the knowledge to select and guide the *appropriate* actions, and (iv) to possess the necessary *skills* to perform these actions.

We have set up two simple models (Figure 1, a and b) in order to describe how the understanding of safe behaviour may be mediated. According to the first, correct behaviour is completely based on a proper understanding of what to do in dangerous situations generally, situational knowledge in this case being of minimal significance; the behaviour in both simulated and real traffic situations would then essentially be the same. According to the second model, correct behaviour is learnt properly in the stuation where it is to be applied, and the behaviour seen in two different, but analogous, situations will be significantly different. But rather then accepting either of these two extreme models, we propose that a combination is a more appropriate way of viewing the relation between cognitive factors and behaviour (Figure 1 c). According to this view, a child's behavioural skills are learnt in many different situations. Each of these has its own, salient specifics, and the child is liable to act according to those in the given situation. As the child develops and attains more knowledge, it becomes better able to see similarities and differences between situations, and to select optimal strategies to deal with the particular situation at hand. Thus, a battery of relevant instances is created, where any new situation may be found to have a counterpart. A substantial part of the child's competence then consists in being able to cognitively apply old procedures to new situations, making possible flexibility of choice and generality of application.

When the performance of young children is brought into a developmental perspective, it is at times difficult to separate cognitive growth from repeated exposure to and practice in the tasks in question. In order to test this we propose to compare young children's performance to the their knowledge and understanding at different ages. We want to assess the quality of the children's answers to questions designed to uncover the understanding of their own actions, and relate this to their actual application of behavioural skills in the relevant situations. In this way, the cognitive strands may (hopefully) be unravelled and distinguished from those stemming from practice in the task.

With respect to the tasks employed for this purpose, we observe the children's traffic behaviour in two analogous situations, where they (i) demonstrate in a model situation how some other skilful individuals perform, and (ii) how they themselves perform the same task in real traffic. We then examine how the behaviour in both situations corresponds. In accor-

dance with model (c) we propose that there will be an underlying similarity in the way the children tackle the two situations, mirroring their basic understanding of the situations and skills involved. But there will also be a considerable difference in performance due to the children's perception of the two situations and their differential requrements. In this way we hope to learn more about how young children cognitively represent potentially dangerous situations, and how this corresponds to what they actually do in these situations.

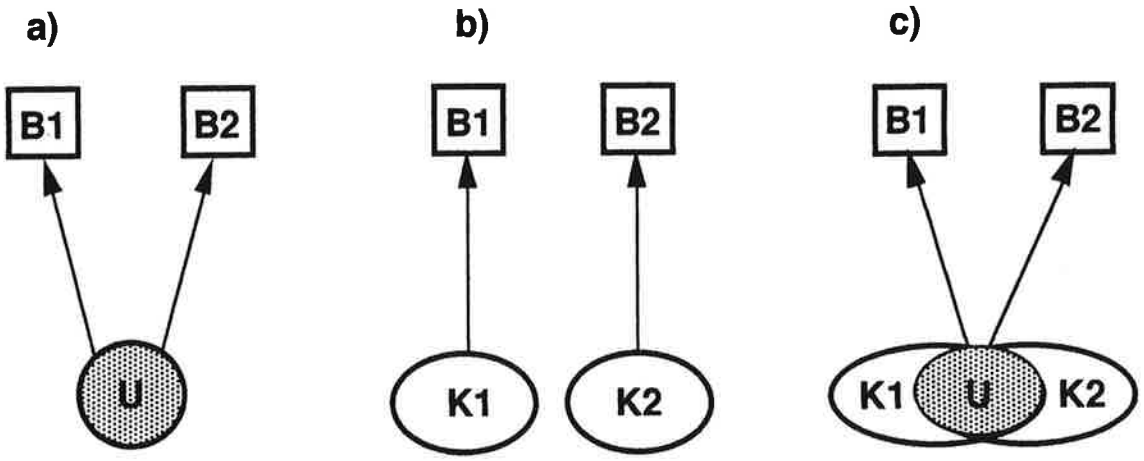


Figure 1. Three models of how a child's situational knowledge (K) and understanding (U) may be related to behavioural skills (B). a) The child's understanding decides entirely how it behaves in two different situations that require analogous behavioural skills. b) The child's knowledge of each of the two situations decides how it will behave, while understanding does not directly affect the behaviour. c) The behaviour in the two situations is the result of both an understanding of how to behave and the specific knowledge of the situations.

2 Method

Subjects. 45 children, 3:6-6:9 years, attending day-care centres in the towns of Halmstad and Lund in the southwest of Sweden, participated in the study. The distributions according to age and sex are shown in Table 1.

Table 1. Observed frequencies for age group and sex for the children in the study.

	Three/Four	Five	Six	Totals
Girl	8	8	5	21
Boy	4	7	13	24
Totals	12	15	18	45

Material. In one part of the study, a *traffic model* made from stiff cardboard, 120 cm X 150 cm, was used (see Figure 2). It contained 3 roads with pavements, 2 crossings with road signs, 3 houses surrounded by lawns and bushes, and a pond. One of the houses was a

day-care centre. There were 2 cars and 3 dolls, representing 2 child pedestrians and 1 cyclist. The set-up and objects in the model were associated to a story about two children, Kalle and Kajsa, and their journey to and from the day-care centre. Other actors in the drama were the child cyclist and the two cars. Kalle and Kajsa and the cyclist were each embodied by the dolls, whose heads could be turned from side to side. The doll representing the focal child wore a small reflector, and the doll on the bicycle wore a helmet.

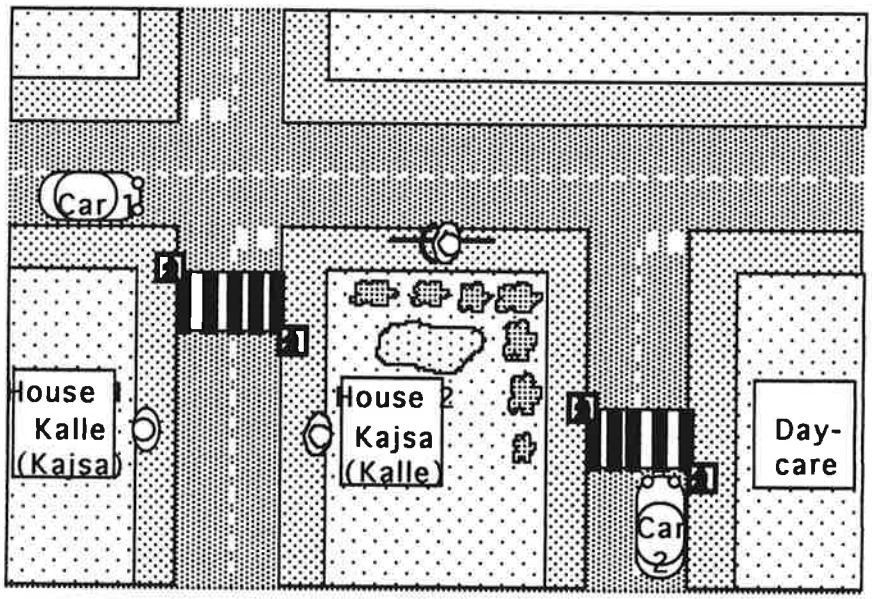


Figure 2. A schematic picture of the traffic model used in the study. The figure shows the initial set-up of the model and the dolls.

Variables. There were two grouping variables, *Age group* (Three/four, Five, Six) and *Sex* (Boy, Girl). Chronological age (continuous variable) was also used in several of the statistical tests. *Safety knowledge and understanding* wer, firstly, assessed in the answers to 4 questions, concerning the function of (i) the *Reflector* and (ii) the bicycle *Helmet*, (iii) understanding of the instruction to be *Careful*, and (iv) the *Explanation* (after crossing Road 1 the first and second time) of why they chose or chose not to cross the road on the zebra crossing. Dependent variables concerned the children's *road crossing behaviour*, represented in three behaviour indices, (i) use of a zebra crossing, (ii) looking for cars, and (iii) waiting at the curb, and were recorded in the model situation as *ZebraM*, *LooksM*, and *WaitsM*, and in the roadside situation as *ZebraR*, *LooksR* (*Waits* was not recorded at the roadside). For the purposes of a final repeated measures ANOVA, we made 2 compacted variables, combining *ZebraM* and *ZebraR* in *Zebra Crossing*, and *LooksM* and *LooksR* in *Looking*. Knowledge of *Road signs* was also included as a fifth knowledge variable here.

Variable coding and transformation: a) The children's answers to the four questions connected with the story were rated as to degree of understanding of the nature and function of the things asked about, and coded as continuous variables (range 0-2): 0 (= *Don't know*) = not knowing or not answering, showing a lack of understanding of the point of the question or giving an egocentric answer; 1 (= *Pre-safety*) = showing incomplete understanding of the point, such as saying that the function of the reflector was to *see* better in the dark, or that of the helmet not to *fall off* the bicycle; 2 (= *Safety*) = showing an understanding both of the

relevance of the question, and of the function of the item or behaviour for personal safety in the traffic situation. b) Road-crossing behaviour in the model was recorded at four points during the journey, when crossing the 2 roads, going *to* and returning *from* the day-care. At each point, three task components were recorded, (i) using /not using the zebra crossing, (ii) waiting/not waiting before crossing the road, and (iii) looking/not looking for cars before crossing. *ZebraM*, *LooksM*, and *WaitsM* were obtained by summing the scores obtained on the 4 crossings. At the roadside, *ZebraR* and *LooksR* were obtained by summing over 3 crossings, making a simple transformation of the latter scores necessary for the variables in both situations to have the same proportional weight.

Procedure. **(1)** In the *traffic model* situation, each child was tested individually by two experimenters at the child's day-care centre. The child was told a story about a child (*Kalle* or *Kajsa*), his/her own age and sex, who goes to the day-care centre with a friend of the other sex (*Kajsa* or *Kalle*) who lives in the house opposite. The child was asked to move Kajsa and Kalle to various destinations in the model as the story progressed, requiring him/her to let the dolls cross the roads. This gave the child an opportunity to demonstrate his/her understanding of traffic devices and rules and of safety behaviour. The child was continually asked questions related to the story, designed to extract further information about knowledge and reasons for acting in particular ways. After the observation in the model, the children's knowledge of 6 road signs, (i) Zebra crossing, (ii) Stop, (iii) Pedestrian lane, (iv) Bicycle lane, (v) No walkin, and (vi) No Cycling, was tested.

(2) In the *roadside* situation (real traffic), the children's behaviour was video-filmed when crossing a lightly trafficked road near the children's day-care centre. The crossing situation, shown in Figure 3, was chosen so as to be analogous to that in the model. The children were accompanied singly to a place near a zebra crossing with an unobstructed view of on-coming traffic in all directions, including the road past the T-junction (2). One experimenter stayed with the child the whole time, giving instructions about what to do, and seeing to it that the child did not run around on its own when there were cars near by. The other experimenter operated the video-camera, and recorded the sequence of events.

The child's task was to cross the road, from the point marked "X" in the diagram, about 15 meters from the zebra crossing, to a tree on the other side of the road. Each child had previously been tested in the model situation and instructed in the importance of following traffic rules. Apart from that, no further instructions were given at the time of observation as to how to cross the road. After crossing and arriving at the tree, the child was told to go back to the point where he/she had started from (X), whereafter the child was told to go to the tree on the other side once again. Thus, each of the children crossed the road three times, and normally the whole procedure took less than 5 minutes. After that the child was taken back to the day-care, and the next child accompanied to the scene of observation. The videofilms were subsequently coded and analysed.

3 Results

Statistical tests were done in *StatView* (Haycock, Roth, and Gagnon, 1993), *SuperANOVA* (Gagnon, Roth et al., 1991), and *SPSS* (SPSS, 1995). The significance level was set at 0.05.

(a) *Understanding of traffic safety and devices.* First we did a MANOVA with *Explanation*, *Careful*, *Reflector*, and *Helmet* as dependent variables, and *Age group* and *Sex* as independent variables. The results were significant with respect to *Age group* (Hotelling-Lawley Trace (8,66) = 0.74, F=3.0, p=0.008), but not *Sex* (Hotelling-Lawley Trace (4, 33)= 0.20, F=1.6, p=0.186). In the 4 2-factor ANOVAs, there was a clearly significant age effect only for *Explanation* and *Reflector* (F(2,36)=7.1, p=0.003 and F(2,36)=6.3, p=0.005, respectively).

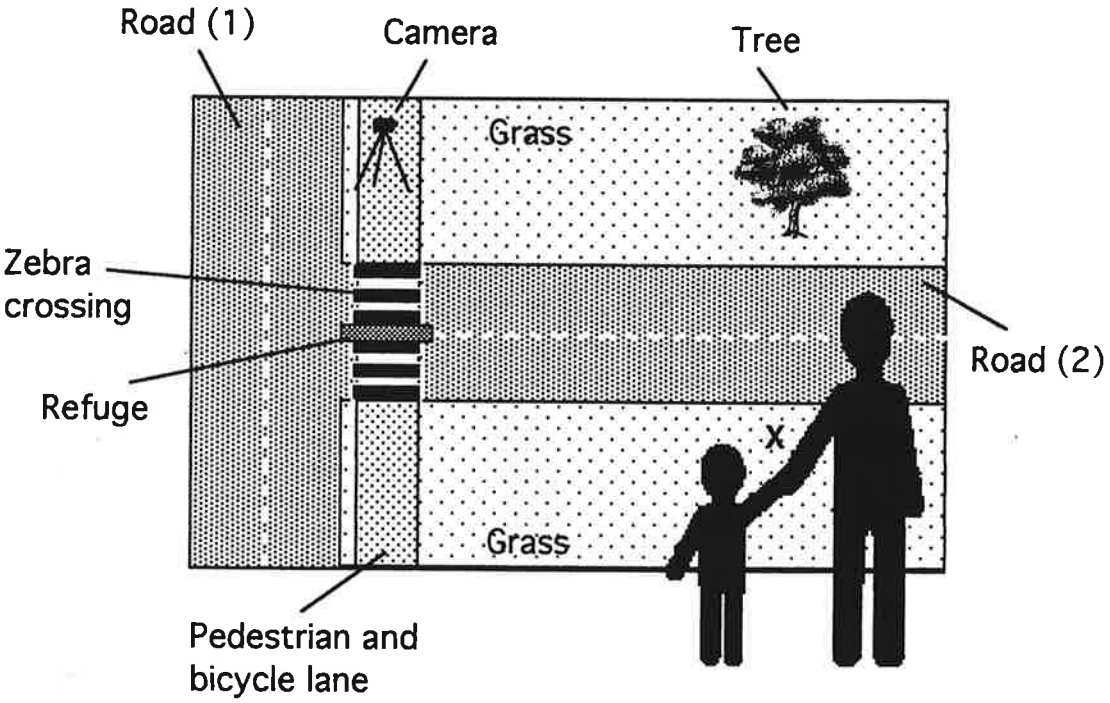


Figure 3. A schematic view of the roadside traffic situation used in the study. The figure shows the initial set-up of the child and assistant. The staring point is marked "**X**".

(b) *Understanding in relation to behaviour in model and at roadside.* Next we subjected all the variables used, the 5 variables concerned with knowledge and understanding and the 5 behaviour variables, to a Pearson correlation, and the results of this to a factor analysis. The best factor solution was with 3 factors, as shown in Table 2.

(c) *Behaviour in traffic situations.* Finally we examined the relation of the children's age to the behaviour variables recorded in the two traffic situations, model and roadside. This was done in 2 separate, repeated measures ANOVAs. A significant difference was found for both kinds of behaviour with respect to *Age group*, with F(2,33)=8.0, p=0.001, with respect to the use of a *Zebra Crossing*, and F(2,32)=6.4, p=0.019, with respect to *Looking* for cars. Use of a zebra crossing was significantly different in the model and at roadside (F(1,33)=63.9, p<0.001), the children using the crossing far more often in the model than at the roadside. Looking around for cars was also significantly different for the two traffic situations (F(1,30)=2.8, p= 0.106), but here the relation was the reverse, with the children looking for cars about twice as often at the roadside as in the model. The mean behavioural scores with respect to age group and behaviour are shown in Figure 6.

Table 2. Exploratory factor analysis of age and ten behavioural and knowledge items, resulting in three main factors (**F1-3**). Factor loadings >.4 are shown.

	Factor 1	Factor 2	Factor 3
Age		,451	,647
Explanation	,939		
Careful		,542	
Reflector			,664
Helmet			,855
ZebraM	,468		,547
WaitM		,936	
LookM		,835	
ZebraR	,473		
LookR		,605	
Signs	,646		,538

Orthogonal Solution

F1: The better the ability to explain the function of the Zebra crossing (and knowledge of road signs), the bigger the probability of crossing the road on the zebra crossing both in model and at roadside.

F2: The greater the age of the child, and the better the ability to explain the meaning of the need to be careful, the bigger the probability of waiting and looking before crossing the road, both in model and at roadside.

F3: The greater the age of the child, and the better the ability to explain the use of safety devices and road signs, the bigger the probability of crossing the road on the zebra crossing in the model.



Figure 4. The children's behaviour in the two traffic situations as dependent on their age. S.E. is shown for each mean score.

4 Discusson

The single most significant determinant of safety knowledge, understanding, and behaviour in the model was found here to be the children's age. We begin by summing up the results from the testing in the model situation with respect to this factor:

Most of the 3/4-year olds had at least a vague understanding that road traffic posed a potential danger to the dolls, they occasionally used a zebra crossing, but seldom looked around or waited before crossing. The majority of the children in this age group did not know why one should use the crossing, but frequently responded with "I don't know", or gave some irrelevant answer, such as "because I wanted to". The children in this youngest group generally did not know why they ought to wear a reflector when walking outside after dark, and while most had an idea that the helmet provided some sort of protection when cycling, they were unsure of why this was so.

The 5-year olds had a clearer conception of the dangers of the traffic, and that danger requires that one adopt certain safety measures. They sometimes let the dolls use the zebra crossings, but looked around for traffic only about half the time, and many of the children in this age group had a problem verbalising an appropriate reason for doing so. More than half of the 5-year olds believed that they could see better in the dark if they had a reflector, and many thought that the helmet was a safeguard against falling off the bicycle.

By the age of six, the children had managed to overcome many of the limitations in understanding demonstrated by the 5-year olds. They no longer believed that the helmet protected them from falling off the bike, and they generally differentiated between falling off and getting hurt. They usually understood that the function of the reflector is coupled to how one appears oneself from the point of view of the car drivers. Generally, the 6-year olds did not understand the reciprocity of communication between participants in the traffic situation at the zebra crossing, and often forgot to let the doll look around when crossing the road.

When we compare the children's behaviour in the model to that in the analogous, real traffic situation at the roadside, we can see both similarities and differences. A major difference was that the children used the zebra crossing in the model far more often than in the real traffic situation. This may have resulted from the differences in the physical structure of the two situations, which naturally was considerable. In the model, the children had a clear view of two well defined zebra crossings, but while the zebra crossing at the roadside was clearly visible, it was also much farther off and in the periphery of the children's visual field at the time when they received the instructions as to what to do.

A clear difference between the two traffic situations was also shown in the tendency to look around before crossing the road. Here, the opposite tendency was shown compared to that for the zebra crossing, as the children looked around for traffic cnsiderably more often at the roadside than in the model situation. There are two possible explanations for this: In the first place, the result may be taken to imply that the looking-around at the roadside is partly an automatic reaction to a situation that the child has been in many times before. Alternatively, the explanation may be that the real situation contains cues that makes the children conscious of the need to look for traffic before crossing the road, cues that are not

available to the same extent in the model situation. It is clear that the factors that decide the quality of the child's behaviour in such situations merit a closer study.

The differences in behaviour that the children displayed in the model and real traffic situations indicate the importance of context for young children's behaviour. The correlations between the analogous behaviour in the two contexts were fairly small, especially for the tendency to use a zebra crossing. However, the factor analysis reveals that analogous behaviour in both test situations is linked together in the factors obtained. One of these includes the children's proper understanding of the need to be careful, and another factor includes the understanding of the need to use a safe place to cross the road, *viz.* the zebra crossing. This dawning understanding of traffic safety forms a foundation on which the children are later able to build a more solid understanding, making it possible for them to accommodate their behaviour to a variety of contexts in a flexible and functional way.

It is obvious from the present results that, at this age, children are not capable of dealing adequately with the complexities of risky situations such as the traffic, and also that their behavioural skills generally do not match what to adults may seem to be a reasonable understanding of risk, safety, and traffic rules. Important components, necessary for dealing with dangerous situations, are missing, both from the children's knowledge and from their behavioural repertoire. Also, it appears that young children's skills, in this case for behaving appropriately in traffic, are to a considerable extent specific to the situation in which they were learned, and the children are not able to integrate their knowldedge into the kind of proper understanding that will enable them to successfully avoid danger.

It may be concluded that, apart from keeping children as far as possible apart from traffic at this age, a thorough training in real, but risk-free, traffic situations is required in order to ensure safe behaviour in risky situations that the children will occasionally have to deal with on their own. It is naive to think that young children can be wholly isolated from potentially dangerous traffic, and foolhardy not to teach them the skills necessary to deal with it.

5 References

Ampofo-Boateng, K. & Thomson, J.A. (1991). Children's perception of safety and danger on the road. *British Journal of Psychology, 82, 487-505.*

Briem, V. (1988). Barn i trafiken: Aktivitetsmönster och säkerhet på vägen till skolan. (Children in traffic: Activity patterns and safety on the way to school.) *Bulletin* **78**, Department of Traffic Technology, LTH, Lund University.

Case, R., Marini, Z., McKeough, A., Dennis, S., & Goldberg, J. (1986) Horizontal structures in middle childhood: Cross domain parallels in the course of cognitive growth. In I, Lewin (Ed.) *Stage and structure: Reopening the debate.* Norwood, NJ: Ablex.

Gagnon, J., Roth, J., Finzer, B., & Hoffman, R. (1991). *SuperANOVA.* Version 1.11. Berkely, CA: Abacus Concepts, Inc.

Haycock, K., Roth, J., & Gagnon, J. (1993). *StatView.* Version 4.01. Berkely, CA: Abacus Concepts, Inc.

Kail, R. (1990). More Evidence for a Common, Central Constraint on Speed of Processing. I: James T. Enns (Ed.) *The Development of Attention. Research and Theory.* Amsterdam : North-Holland.

Molen, H. H. van der (1981). Child pedestrian's exposure, accidents and behaviour. *Accident Analysis and Prevention, 13,* 193-224.

Pfeffer, K. & Barnecutt, P. (1996). Children's auditory perception of movement of traffic sounds. *Child Care, Health and Development,* **22**(2), 129-137.

Phinney, J., Colker, L., & Cosgrove, M. (1985). Literature Review on the Preschool Pedestrian. *US Department of Transportation, Literature Reviews, DOT HS 806 679.* Springfield, Virginia 22161: National Technical Information Service.

Rothengatter, J.A. (1981). *Traffic safety education for young children: an empirical approach.* Lisse, The Netherlands: Swets & Zeitlinger B.V.

Ryle, G. (1949). *The concept of Mind.* London: Hutchinson.

Salvatore, S. (1973). The ability of elementary and secondary school children to sense oncoming car velocity. *Highway Research Record,* **436**, 19-28.

Sandels, S. (1970). Young children in traffic. *British Journal of Educational Psychology,* **40**, 111-116.

Sandels, S. (1977). *Skandiarapporten I: Barnet i trafikmiljön. (The Skandia Report I: The Child in the Traffic Environment.)* Stockholm: Skandia.

Siegler, R. S. (1978). The origins of scientific reasoning. In R. S. Siegler (Ed.) *Children's thinking: What develops?* Hillsdale, NJ: Erlbaum.

Siegler, R. S. (1981). Developmental sequences within and between concepts. *Monographs of the Society for Research in Child Development, 46* (2, Serial No. 189).

SPSS (1990). *SPSS for the Macintosh 4.0.* Chicago, Ill.: SPSS, Inc.

Vinjé, M.P. (1981). Children as pedestrians: Abilities and limitations. *Accident Analysis and Prevention, 13,* 225-240.

Zelago, P. D., & Shultz, R. R. (1989). Concepts of potency and resistance in causal prediction. *Child Development, 60,* 1307-1315.

Observation of crossing behaviour in the vicinity of pedestrians subways

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The proportion of pedestrian accidents in Hungary is high and practically unchanged in the last 5 years: it is 22-23% of the total number of accidents. 29% of accidents occurring in built-up areas and 9% of those occurring on rural roads are pedestrian accidents.

50% of the pedestrian accidents are caused by drivers. In 1995 29% of the pedestrian accidents occurred on crosswalks, 8% in junctions without a crossing facility, 2% between the pedestrian refuge island and the pavement, 4% at stops of public vehicles and 57% on other sites. Among 'other sites' are the surroundings of pedestrian subways, where crossing on the surface is especially dangerous. At these sites the drivers don't count with the appearance of pedestrians, they don't accept their presence and right of crossing there and they expect the pedestrians not to restrict their proceeding. [1]

The construction of pedestrian subways is very expensive, but these facilities assure complete safety to their users. Experience shows that many pedestrians don't use the subways and this fact clearly deteriorates their protecting value.

In order to influence pedestrian behaviour, it is important to reveal the characteristics of crossing behaviour, the motives for not using the subways, and the traffic conflicts taking place while the pedestrians cross on the surface. [2]

1 Observation method and sites

1. The pedestrians crossing on the surface were *video-taped*. The observations took place during daytime, in dry weather, in good visibility conditions. The camera could not be seen by the pedestrians. The complete crossing of a selected pedestrian was filmed even then, when another pedestrian started to cross. When evaluating the recordings, the whole duration of the crossing was measured, including the waiting time on the pavement. The direction and speed of pedestrian movement were described (e.g. walking smoothly, in a hurry, coming to a sudden stop, starting to run). The head movements for orientation were also observed.

2. Some of the pedestrians (selected randomly) were *interviewed* right after illegal crossing. The most important objective of the interviews was to reveal the motivations of pedestrians not to use the pedestrian subway, but decide on the dangerous crossing on the surface.

The observation of pedestrian behaviour took place in Budapest, at two sites with high traffic volume, where the pedestrians crossing on the surface have to cross multi-lane roads and many of them are not using the subway, in spite of the inherent risk.

Both sites are near railway stations, with a relatively high number of people coming from the countryside, not being familiar with the surroundings. At both sites the subways are connected to metro stations.

Site I

The pedestrians crossing on the surface cross the two-direction, 2x3 lane road parallel to the subway. The inner lane leads into an overpass and leads the traffic down from there.

If someone wants to cross the road on the surface, he exposes himself to high risk. The vehicles driving up the overpass cause frequent congestion, while those coming down proceed at a speed of 50-60 km/hour or more. It is very dangerous that in one traffic lane traffic is very slow or standing, while in the neighbouring lane vehicles are approaching at high speeds from the opposite direction.

There are no escalators and there is no ramp. Crossing through the subway takes 2 minutes, at a comfortable pace.

Site II

The pedestrians crossing on the surface have to cross a two-direction, 2x3 lane road here, too. In the middle there is a two direction tramway, with a small refuge island on one side, making crossing safer. The pedestrians can wait here until traffic has passed.

There is no refuge island on the other side of the tramway. A dangerous situation may emerge when the crossing pedestrian halts at the edge of the inner traffic lane, to give priority to the tram. In such a case, motor vehicles are passing very close behind the pedestrian and the tram is passing in front of him/her.

At both sides of the 2x3 lane road, there are bus stops in the outer traffic lanes. The placement of the pedestrian subway is unfavourable, because if the pedestrians are crossing the subway to reach the bus stop on the other side, they need to cover a 120 m longer way than the way on the surface.

On one side of the road, the subway is provided with a ramp, while on the other side there are only stairs.

The traffic volume of the road is high and almost continuous in peak hours. Congestion is frequent, traffic gets slower then, sometimes it gets to a halt, which favours the pedestrians intending to cross.

When the traffic volume is lower, there are gaps in traffic because of the traffic signals, making the crossing of pedestrians possible.

2 Results

2.1 Behaviour characteristics of pedestrians crossing on the surface

On site I there were two observation periods in the morning hours and two in the afternoon. The number of illegally crossing pedestrians was the highest during the afternoon peak hours (between 15.30 - 16.30). In this period 18 recordings were made, with 26 illegally crossing pedestrians. During the whole investigation period, in 58 recordings 90 illegally crossing pedestrians were observed.

The estimated age of the majority of pedestrians observed was between 16 and 35. The estimated age was 60-70 in three cases (3%). There were 63 men (70%) and 27 women (30%). 33 pedestrians were crossing alone, the majority however in pairs. 41% of the men, but only 28% of the women were crossing alone.

On site II there were two observation periods in the afternoon hours, between 15.15 - 16.45 and 16.50- 17.50 respectively. During the whole investigation period, in 52 recordings 90 illegally crossing pedestrians were observed, too.

Out of the pedestrians illegally crossing, the majority belonged to the age group of 15-20 year olds. The ratio of those over 60 was about 6%.

Of the pedestrians observed, 49 were men (54%) and 41 were women (46%). At this site, considerably more women were not using the subway, than on the other site. The number of pedestrians crossing alone was 29; 37% of the men and 27% of the women were crossing alone. Because of the relatively high number of illegally crossing pedestrians, pedestrian groups were formed.

There were no serious conflicts on any of the sites. The pedestrians crossing on the surface were completely aware that they had to give priority to the vehicles, they had to adapt their movements to the vehicles. The drivers yielded to illegally crossing pedestrians only in such cases, when traffic jams emerged, and the movement of vehicles was very slow. (Except for one case, when an elderly man was crossing with a walking stick in hand.)

The behaviour observation of young pedestrians showed that they were practised in illegally crossing on the surface. Their movements didn't indicate signs of fear or anxiety. They got used to danger, or they didn't perceive it at all. They were trying to cross in such a way that the time delay be as small as possible. It could be observed several times, that they were walking in many cases on the lines separating the lanes, parallel to traffic, making use of the time during which they had to yield to vehicles. Some of them seemed to tackle the dangerous situation as a challenge, as if they had enjoyed zigzaging among the vehicles.

At site I the majority of the crossings took less than 1 minute. (The longest time of crossing was 77 seconds, the shortest 9 seconds.) In the first phase of the crossing - to the median of the road - the pedestrians were not running. They were looking around and they were

inclined to be waiting for 30-40 seconds with patience. In the second phase of the crossing however, patience was lost and the majority of the pedestrians began running.

At site II, one third of the crossings took less than 1 minute, two thirds took more than 1 minute. The shortest crossing time was 20 seconds, the longest 2 minutes and 54 seconds. The pedestrians usually stopped on the narrow refuge island near the tramway.

The most dangerous behaviour could be observed in the cases of pedestrians who wanted to catch the oncoming bus on the other side of the road. 36% of the illegally crossing pedestrians belonged to this group. Many of them were running, or were crossing the road diagonally. The wish to catch the bus is a strong motivation, which raises the threshold of risk taking and adds to the disregard of danger. In cases when the pedestrian is able to catch the bus, the illegal behaviour will be rewarded and as a consequence of this it will be repeated.

2.2 Motives of illegal crossing

At site I, interviews were conducted with 40 pedestrians crossing on the surface (26 men, 14 women). The average age of the pedestrians interviewed was 28 years, the youngest being 11 and the oldest 63 years old.

8 of the pedestrians were going to catch a train, but only 3 said that they had not used the subway because they wanted to spare time. Further 4 persons reasoned that they were not familiar with the surroundings and didn't notice the entrance to the subway. A 61 year old lady was carrying large, although not heavy packets and didn't want to use the stairs because of this.

Four of the pedestrians crossing illegally (one from Budapest and three from the countryside) were losing their way in the subway, came out at a wrong place and didn't want to go back, they felt it better to cross on the surface. A 21 year old woman reported not liking to use the subway, because of claustrophobia. She doesn't feel it safe to cross on the surface, but she is very cautious, if it is necessary, she will wait for several minutes for the appropriate time to cross.

There were only 2 pedestrians referring to walking difficulties. They were not old: a 47 year old man, and a 50 year old woman.

The illegal behaviour of the other pedestrians (25 persons, 63%) was motivated fundamentally by the desire for comfort. These pedestrians are healthy, they have no mobility handicaps. The majority of them is well acquainted with the surroundings and often crosses the road avoiding the subway. Their primary motivation has been comfort and not time spare. At the same time it was this group that attributed the highest time gain to illegal crossing (5-10 minutes). They were well aware of the illegality of their crossing.

To the question „What changes in the crossing facility would be needed so that you use the subway?", the majority answered that escalators should be built in. Many of the respondents

argued, that the exits and the surface destinations should be marked in a better way. The subways should be kept cleaner and should not be narrowed down by occasional sellers. Several pedestrians mentioned with some self-criticism that not the traffic environment but they themselves should change.

At site II, 22 of the illegally crossing pedestrians (11 men and 11 women) were interviewed. The average age of the respondents was 33 years, the youngest being 15 and the oldest 72 years old.

According to the majority of the pedestrians, the subway was so far away that it can be regarded as „normal" behaviour not to use it. They don't regard crossing on the surface to be against the rules. This may explain the high number of illegally crossing women at this site.

11 pedestrians getting off the metro wanted to catch a bus on the opposite side. 4 of them decided to cross on the surface, because of greater chance of catching the oncoming bus, which might mean time spare for them. 6 pedestrians reported that they never used the subway, they would approach the bus stop on the surface. For them, comfort is the primary motivation, time spare is only secondary. A 20 year old woman reported that she usually used the subway and this was an exception that she had shortened the way because of heavy bags.

Another group (7 persons) were motivated by comfort only. They were not travelling, they were living in the vicinity of the subway.

Four pedestrians chose to cross on the surface because it was difficult for them to walk to the subway. Those people with mobility handicaps are very cautious, they wait for the appropriate time gap. They are familiar with the surroundings.

Most of the respondents were suggesting that the bus stops should be nearer to the subway, or a pedestrian crosswalk leading to the bus stops should be established.

3 Conclusions, recommendations

1. Of the pedestrians not using the subways, the proportion of young people is the highest. They are healthy young people, with no handicaps. Among those not using the subways, a very small proportion (3-5%) are elderly, physically handicapped people.

2. The primary motivation for not using the subways is the desire for comfort, followed by real or believed time spare. In the case of young people, important motives are risk taking, seeking excitement, demonstrating skills.

3. The subways should be constructed in such a way that they offer maximum comfort. It is important to build escalators and ramps. The traffic spaces should be large, congestion should be avoided. Lighting should be near to natural and cleanliness is very important.

4. The exits should be better connected to the stops of public transport and to parking lots. To reach these through the subway should be more comfortable and quicker than on the surface.

5. It is very important to inform the traffic participants on the surface directions and destinations. It is not sufficient to indicate the names of the streets, but the pedestrians should be informed also about the odd or even house numbers and important public buildings.

6. Police enforcement should pay much more attention to pedestrian behaviour. Many people could get accustomed to the use of subways if warning and fines would be more frequent.

The majority of the conclusions and recommendations seem to be evident. However, it is astonishing, how often these principles are neglected, how rarely the fundamental needs of pedestrians are taken into consideration when shaping the traffic environment.

Acknowledgement

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References

[1] Draskoczy, M., Hyden, C.: Pedestrian safety measures - past and future. Proceedings of the 6th Workshop of ICTCT „Pedestrian problems", Prague, 1994.

[2] Siska, T.: Nem biztonságos helyen áthaladó gyalogosok magatartási sajátosságainak kutatása. Konzulens: dr. Holló Péter. (Research into the behaviour characteristics of pedestrians crossing at dangerous sites.) Research report, 1995, commissioned by the Institute for Transport Sciences.

Search Strategies in Simulated Traffical Situations Investigated with a Stationary Eyemarker Equipment.

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Road users' search strategies on slides of real traffical situations were investigated with a stationary device called the "Eye- Catcher" developed by Risø National Laboratory, Denmark (Hansen, 1990; Hansen, Andersen & Roed, 1995). The slides revealed road direction signs in "natural" settings and turn-left situations in crossroads, imposing a conflict situation between car drivers and cyclists.

The aim concerned the usefulness of the "Eye-Catcher" as it was implemented in the interactive exhibition at "Experimentarium", a science museum in Copenhagen, the applicated software, and more concretely to investigate search strategies on "complex pictures" i.e. slides of traffical situations. The project was initiated and financed by The Danish Road Directory.

Car drivers' scanning of direction signs was chosen as a theme for the concrete project. Aims and problems were as follows:

- How is the scanning pattern of roads users influenced by the number of information units on a directional sign table or on a system of directional sign tables.
- How and to what extent are route numbers and symbols used in the road users' scanning pattern.
- To what extent is the road user distracted by interfering bill boards, and what is the impact on reaction time and typical scanning patterns.

It is a further aim of the project to be able to organize directional signs and their environment so that they will serve road direction service as well as traffic safety in an optimal way.

Furthermore an investigation of car drivers' orienting behaviour to cyclists, during left-turning situations, was planned on a minor number of signs. The aim was to explore how car drivers scan the scene for other road users, especially vulnerable road users like cyclists, whether they observe cyclists if there are other cars in the visual field, and whether their behavioural choice reflect the observation of the cyclist.

Theoretical references

Agg (1994) investigated direction sign overload in laboratory experiments. The subjects were instructed to "follow a truck in the inner lane". On slides road directional signs were projected so that they seemed placed in the left side of the road (left hand driving). Furthermore they were instructed to localize a given destination on the direction sign and react by pointing out the direction, one should drive to reach the destination. Reaction time and choice of direction were registered. Eye movements were not redorded. She

found a complex relationship between an impact of number of destinations and route numbers on reaction time. Among other things : When the number of destinations exceed six, the mean reaction time for tables with three route numbers will exceed the reaction time of tables without route numbers. On the whole, she finds an effect of numbers of information units including: Destinations, route numbers and symbols (together with other specific information of a table, which are not found on Danish road direction signs). Her concept of information unit is used in the present investigation in a slightly generalized form - here also including distances, appearing on Danish road direction signs.

Theeuwes (1990, 1991, 1995) characterizes an active visual search as an endogenous, top-down controlled process, where the attention is purposely (or motivationally) directed to particular features relevant for the search task. The perceptional selection is task dependent. His results contradicts the common idea that conspicuous objects automatically attract attention. These results have inspired to investigate how robust the search behaviour can be, when subjects are exposed for distractors. In his experiments Theeuwes uses stilized drawings as stimuli. Eye movements are recorded.

Luoma (1984 a, 1984 b, 1988, 1989) has investigated, whether bill boards influence car drivers' eye movements and perception of road signs. In several experiments subjects were not given specific search tasks, but asked to drive and observe as normal during their driving. After certain intervals they were asked what they had observed. Among other things he found, that when a road sign and an advertising bill board are within the same visual field, the perception of the road sign is disturbed. The kind of orienting behaviour Luoma's subjects reveal, might - to a greater extent - be characterized as bottom-up or data driven - concerning the perception of the road signs - in this investigation called "attentional strategy".

Hagenzieker (1992), from whom inspiration for this research project's design was derived, recommended supplementing the eye movement data with other dependent variables. As an indirect attempt to fulfill this recommendation, the subject is in the present investigation requested to identify a specific target.

Generally, distinguishing between general and local scanpaths (Groner, 1988; Zangenmeister, Sherman & Stark, 1995) has seemed more relevant. Never the less, it hasn't been technically possible to apply the necessary methods of registration and analysis to this context. The scan path research, however, has been an inspiration in the search for more global search strategies through other means.

Slides of "natural" road table environments and traffical situations of conflicts in road crossings were used in the present experiment. The subjects were provided with instructions to identify a target through selective search on relatively "complex" pictures. Hence, finding comparative settings in the available literature has been difficult.

Equipment and methods

The guests of the science museum voluntarily served as subjects in this experiment - in the role of "one-and-for-all-subjects" (each subject one trial).

The setting was like this: The subject is seated at an adjustable chair and her head situated in a goggle-like support. The subject is instructed by continuous text based menus on a large screen, of the same size as the slide projection screen. The automatic calibration process is conducted by an interactive instruction to follow some fixation points as they appear on the screen. Provided the calibration comes off, the subject is guided through some optional tasks. The subject is able to respond visually by fixating a so-called "eye-con", which is activated after a certain fixation time. In this manner the subject visually can reply to questions concerning age, sex, driving experience, and preferred means of transportation.

A search instruction is subsequently presented on a separate screen picture. Generally the subjects are told to imagine themselves sitting behind the wheel in a car. At the road sign pictures they are instructed to find a certain destination, and at the crossroads pictures requested to turn left as soon as possible. The slide is then projected and the subject's subsequent eye movements wil be recorded. Provided the subject fixates the target area (on the road sign pictures) or the respond squares (on the crossroads pictures) the projection is stopped. And if the subject does not find the target, the projection is terminated after 10 seconds. Immediately after the projection as feed-back, the subject was shown the recorded eye movement depicted on a photo-CD copy of the slide.

The supporting software manages registration of eye positions (but not fixations), engaging a sampling frequency of 55. m.sec., and the reaction time of each task. A so-called "Report Program" shows individual eye movement patterns, superimposed on (a copy of) the inspected picture. The program works as a kind of "animation program", giving a demonstration of the eye movements in actual, half-, quart- or 1/8 the velocity of the action. The resulting eye movement pattern is then transferred and superimposed to a copy of the projected picture and subsequently imported into a worksheet program. Through this the eye movements may then enter into a qualitative documentation. Also, data can be analyzed statistically - individually and for the whole sample - in a worksheet program. This program produces matrices in 12 x 16 squares according to the positions of the eye.

The "Eye-Catcher", it is emphasized, only registers the position of the eye at the time of the actual recording. This means, that two different possible means of positions can be recorded, namely an actual fixation, i.e. when the eye is immovable, and as the eye moves at the time of recording. As such, there is no distinguishing between fixations and saccades as is usually the case. Most fixations last 100-350 m.sec., thus all fixations are recorded during the sampling sequence (every 55 m. sec.). Thus, the distinction between fixations and saccades apparently has no great significance in the present case.

The number of destinations, occurrence of route numbers, symbols and distractors (roadside bill boards) on the road sign pictures are systematically varied in a factorial design. On the crossroads pictures 6 variants appear, of which 4 are recorded "live" and two are with instructed actors.

Method

A driver searching a road sign almost always has a specific purpose in doing so; often the purpose is to find a destination (e.g. "Roskilde"). In order to simulate such orienting behaviour, the subject is exposed to searching tasks that evokes a similar act using the exposed image. In the initial instruction he's guided towards a certain target in the picture, which may be a name of a town on a road direction sign. Having found the target, the subject must fixate this for a moment, whence the system records the answer and terminates the exposure. Supplementary information may be given, requesting that the subject searches through the route numbers, e.g. "You proceed to Roskilde by route 155" or through symbols, e.g. "You are going tired ad are looking for accomodation".

The subject is encouraged to "read" the traffic and act quickly in the crossroad pictures; "Turn left as soon as possible. Will you follow the red car and turn now ?"

During the course of an experimental series, one would typically expect the subject to develop faster reaction time as well as more efficient searching strategies. The subjects from the science museum were only exposed to one picture each, and may as such all be considered to be "novices" and the data free of learning effects. Supposedly, this characteristic trait differentiates these data from most other experimental data referred to in the literature. The design only depicts results "between subjects".

649 subjects participated in the experiments. More than half the data from the subjects were inadmissible in the quantitative analysis. They were either too poorly calibrated. or the subjects hadn't read/perceived the written instruction, thus they didn't inspect the image as instructed, merely gazing with no specific purpose of doing. The results from 276 subjects with reliable search patterns remain.

Results

Quantitative analysis of the effect of the experimental design's variables during the search time

A quantitative analysis was implemented on the road sign images' effect on the variables of the experiment's design. How does the systematic varied independent experimental variables of the design; i.e., number of destinations, presence as well as absence of route numbers, symbols and distracting elements, influence the only dependable variable, i.e. the search time ? Presumably, the more destinations and information contained within a road

sign environment, the longer the search time. Further, it is presumed that the presence of route numbers, symbols and distractors will prolong the search time.
The results were analyzed - mainly by using t-tests.
Initially, the effect on the number of destinations is analyzed:

t-tests for Independent Samples of DESTINA number of destinations

Variable	Number of Cases	Mean	SD	SE of Mean
Reaction time in seconds				
DESTINA >= 7	105	**3,2476**	2,307	,225
DESTINA < 7	171	**2,5731**	2,174	,166

Mean Difference = ,6745

Levene's Test for Equality of Variances: F= ,700 P= ,404

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	2,44	274	**,015**	,276	(,131; 1,218)
Unequal	2,41	210,15	,017	,280	(,123; 1,226)

The cutpoint between the two distributions has been set at >= 7 destinations, which splits the sample in approximately equal parts. If the number of destinations equals or is larger than 7, the average search time augments with 674 m. sec. The result is significant. As the hypothesis is one-tailed, i.e., the more destinations, the longer the search time, this contributes further to the high significance of the result (one-tailed p = 0,008).

Although an observed small effect of 79 m.sec. on the occurance of route numbers in the sign environment is indicated, this isn't significant (one-tailed p = 0,38).

An average increase of reaction time of 840 m.sec. is seen in the presence of symbols, indicating high significance (one-tailed p = 0,001).

As an attempt at a joint expression of the attentional strain, each image were graded concerning the total number of information of the road signs. The count/grading included all the following elements: destinations, route numbers, symbols and indications of distance. Information in the depicted images varies between 3 and 26. Splitting the sample in the value area by 13 elements of information, there is a difference of 679 m.sec. (one-tailed p = 0,002). Splitting the sample in approximately equally sized groups of subjects - 16 elements of information -, there is a difference of 1000 m.sec. (two-sided p = 0,000). Thus, the hypothesis of the larger amount of information contained within a road sign environment, the longer the search time is confirmed. Prolonged reaction time may be interpreted as an expression of proliferated cognitive load.

Surprisingly , there is no indication of the effect in the presence of distractors, operationalized as bill boards. Actually, the effect is negative, since the presence of a distracting element reduces the reaction time with 128 m.sec.; a difference that none the less isn't significant (one-tailed p = 0,32). The explanation may be, that many other circumstances apart from the operationalized distracting element might have a distracting influence, and that the depicted situations may be so diversified, that there is little sense in comparing the influence of distracting element across the situations.

Fortunately, within the sample there are ways to scrutinize this paradox at closer range. Two of the depicted pictures are identical except for a distracting element (a bill board), superimposed in its "twin-image" by photo manipulation. An other pair of images, both depicting the same crossroad from slightly different angles, though one contains a distracting bill board of a local flea market. Instructions to each twin-picture pair is evidently identical. These 6 pictures were thus analyzed apart in reference to a possible distractional influence. The effect turned out to be exceedingly significant, namely 1417 m.sec., or more than the double search time on images with distracting elements (one-tailed p = 0,003).

Hence it is concluded that on dias depicting actual complex road sign environments has been possible through a systematically varied design to indicate significant search time effects on numbers of destinations, of presence of symbols and of collected elements of information (numbers of information), but not on presence of route numbers. Influence of distractors hasn't been generally demonstrated, except through a separate analysis of images of identical tasks and depicting identical versus approximately identical situations.

Qualitative categorizing as well as qualitative and quantitative analysis of patterns of eye movement.

The individual data has been categorized "manually" in a qualitative manner according to a series of categories of which the following 7 will be noted henceforth: status (OK, possibly adequate, dispensable), calibration (OK, somewhat "awry" but interpretable, dispensable), number of times selected image elements were looked at, number of times the experimentally induced distractor was looked at, number of times naturally occurring distractors were looked at, characteristic pattern of eye movement, and whether the task was completed correctly/falsely.
The term "looked at" refers to the outcome of the following "manual" categorizing procedure: On every test image a number (6-7) of the image's most significant or prominent features/areas are identified and numbered. One of these areas is the target area, that the observer will be requested to find and fixate on. Others may be distractors, another part of the road sign, an approaching vehicle traveling in the opposite direction, etc. During the slowest section of the animation speed in the "Report-program" (1/8 of the actual speed of eye movement), there is manually registration of the position of the gaze in a numbered area of the image. As the gaze is directed outside of this square and then redirected into it, another registration takes place of the "gaze", and when directed into another area of the

image, this too is recorded according to the number of the new square. It hasn't been possible to record the duration of time of the gaze.
This procedure is exceedingly time consuming, so that only 2 roads sign- and 2 crossroads images were analyzed. Data from 74 test subjects were processed. Only data where status and calibration is OK were included in the analysis, and all the "attention profiles" - that is, subjects who didn't fixate the target - were discarded.
Identification of three different search patterns was successful, described this way:
1. **Direct** - in which the test subject moves the eyes directly from the point of departure towards the goal,
2. **There-and-back** - the attention pattern here is simple as well, though contrary to the direct pattern the round-trip involves a single regression.
3. **Star** - describes a more complex pattern, in which the picture elements are searched and often re-checked in various successions. Sometimes the star shaped pattern may be seen in attention scans as well.
4. **The Merry-Go-Round** - signifies a tour among all the prominent elements of the image, sometimes repeatedly, typically aimlessly. Thus, the Merry-Go-Round pattern has been characterized as an attention pattern.
It is extraordinary - albeit perhaps trite - that an eye movement pattern may be identified as respectively a search pattern versus an attention pattern exclusively on the basis of its shape. Even without the researcher's knowledge of the task instruction.
Notably, as yet the above mentioned descriptive categories cannot completely be distinguished on their own. Especially problematic is the unambiguous distinction between the star and the Merry-Go-Round patterns, as signified by the frequency table below: Two subjects have used a Merry-Go-Round pattern, but their orientation behaviour has been recorded as search strategy.
Pattern characteristic on two road signs and two crossroads images:

Value Label	Value	Frequency	Percent	Percent	Percent
Merry-Go-Round	1,00	2	2,7	2,7	2,7
Star	2,00	40	54,8	54,8	57,5
There-and-back	3,00	15	20,5	20,5	78,1
Direct	4,00	16	21,9	21,9	100,0
	Total	73	100,0	100,0	

Half of the subjects uses a star-shaped scanning pattern, app. 20 % the there-and-back pattern, app. 21 % the direct pattern, while only 2 test subjects or 3 % uses the Merry-Go-Round pattern.

The two road sign pictures:

On the road sign images there is a slightly different distribution of search patterns. as 1/3 use a star pattern. barely 40 % use the there-and-back pattern, a little over 1/5 use the direct pattern, - signifying a tendency towards a simpler search pattern.
A clear effect of the search pattern on "number of fixations" (i.e. number of times the gaze was directed towards a square) appears, in that the star and the Merry-Go-Round employs

just short of 5 fixations more than - i.e., more than the double amount as - the direct and the there-and-back patterns. The result is highly significant (one-tailed p = 0,001).
The search time, too, was affected by the search patterns. The star and the Merry-Go-Round pattern takes 3184 m.sec. longer - i.e., 3 times as long - than the there-and-back and the direct pattern (one-tailed p = 0,001).

The two crossroads pictures:

The dominating search pattern on the crossroads pictures was the star (app. 71%), close to 20 % uses the direct, while 7 % employs the there-and-back pattern. No Merry-Go-Round pattern was recorded. A tendency towards a predominantly more complex search patter was found in this case.
Almost 6 fixations marking the difference - i.e., app. 2,5 times as many - being employed within the star pattern, as opposed to the amount used on the there-and-back and the direct pattern. The result is highly significant (p = 0,000).
The star pattern takes 2950 m.sec. more than - i.e., more than the double amount of time - the there-and-back and the direct pattern (p = 0,000).

Summary on patterns of road signs- and crossroads pictures:

As far as the road sign pictures is concerned, the search behaviour is characterized by relatively fewer fixations (6,53) and briefer time spans (2530 m.sec.), as opposed to 7,9 fixations and 4520 m.sec. on crossroads pictures. The text bar on the crossroads pictures is no doubt a contributing cause to a large proportion of this difference, but there is further evidence indicating, that the crossroads tasks were more difficult to complete.
In both counts the number of fixations when taken as one was 2-2,5 times as big.
Likewise, the search time was 2-3 times as long on the star and the Merry-Go-Round compared to the there-and-back and the direct patterns.

When the sample is divided in two almost equal parts (7 fixations), the search time escalates 2,5 times or at a mean of 2145 m.sec. (p = 0, 000).

The correlation between number of fixations and search time is relatively invariant across several tasks and contexts. The possible interpretation of this is, that typically the driver employs a brief inspection of one or more of the picture's elements, possibly repeatedly, instead of a more thorough inspection of each element separately. The discovery that when increasing the number of times the subject looks at the squares of the picture, the search time is likewise increased may seem banal. But prior to the investigation, this was by no means evident. The subject might carefully have examined each element of the picture separately.

Looked at, but not perceived.

Working with the material, it has been possible to identify situations, where the subjects has "looked at, but not seen" one or more necessary objects in order to complete the task.

The interpretation of whether the subject had "looked at, but not perceived" is actually facilitated through the introduction of a conflict between some of the elements in the instruction, e.g. between the wish to make an immediate left turn and the desire to let an approaching, not very visible weak road user traveling in the opposite direction pass.

It is (maybe) permissible to conclude in case of a correctly solved task, that the subject has "looked and perceived" when in fact the eye has been fixated on the "target object", and " not looked at, but perceived" in the case where the subject didn't fixate the target object. In case of a false answer in may be concluded, though, that the subject has "looked at, but not perceived", when the target object has been fixated, and "not looked at and not perceived", when the target object hasn't been fixated.

The amount of material analyzed so far is, however, so small, that statistical adaptation is inadmissible. Qualitatively, though, the following example may be given:



The instruction for this picture is: "Turn left as soon as possible. Do you want to turn now?" As seen, the text bar contains a resume of the instruction: "I turn immediately, as soon as the white cars have turned away". The critical detail - the target - is a cyclist, situated directly behind the right-turning car.

The subject employs a star-shaped search pattern. Initiating, he scans the text bar briefly, then the approaching left-turning car traveling in the opposite direction, proceeds oscillating a few times between the target (the cyclist) and the right-turning approaching car traveling in the opposite direction, a single detour to the approaching left-turning car, also traveling in opposite direction, and then finishing off by reading the text bar and choosing the answering space by "yes".

In advance the answer is categorized as false, because there is imminent danger of collision with the approaching cyclist. Despite the subject's thorough inspection of all relevant elements, he chose an incorrect solution. This action may be interpreted as an example of "looked at, but not perceived".

Alternatively, it may be argued whether the subject hasn't perceived the risk of conflict, expects the cyclist may keep back, etc.

Discussion

Method: The "Eye-Catcher" having been placed as an element of entertainment at a science museum has been problematic. In part because the calibration appeared to be extremely vulnerable. Only data from 20% of the persons who attempted to use the "Eye-Catcher" was recorded. Among those who passed the automatic calibration task successfully, some weren't able to sit absolutely still during the preceding process, so that their data was rejected or this at least provided strenuous interpretation of these data. Furthermore, a number of subjects had "overlooked" the written instruction, and in doing so, didn't know which task to complete, when the picture was exposed. As previously mentioned, their data are categorized as "attention strategies". All in all, this signifies a vast loss of data.

Despite these reservations, never the less reliable data from 276 subjects remain. These data are remarkable at least in respect of two aspects: First, they have no underlying learning effects. On one hand, this complicates the comparison of these data to other reported data. On the other hand, one might appreciate that this unites these data in a sort of virginal as well as unsophisticated state, which is commendable. An additional trait is that through their comparison to other collected data, more universal traits of search strategies are revealed. Possibly the most remarkable finding is, that a design producing purely "between subjects" data reveals discoveries of a more general nature.

Primarily, the more global traits are here considered to be:

- That the elements in the pictures are typically focused on several times at short velocity instead of being scrutinized thoroughly element by subsequent element.
- That great individual differences in search strategies appears.
- That the search strategies through great approximation simply on the basis of their shapes may be distinguished from attentional strategies.
- That the effects of cognitive strain is detected in such diversified and complex images (despite the vast difference in the contexts of the images) in the form of number of information units
- And even more notable; that single parameters such as number of destinations and prevalence of symbols is manifest.

Contrary, it seems there is no instances in support for noting the absolute reaction time.

At a more general level of abstraction, one might possibly indicate the parallels between top-down directed, endogeneously controlled visual selection, the global scanpaths and the presently caraterized patterns of orientation: The direct, the Merry-Go-Round and the star search patterns - as well as the bottom-up directed, exogenously controlled local scanpaths and the Merry-Go-Round attentional pattern presently introduced.

References

Agg, H.J: "Direction Sign Overload"; Transportation Research Laboratory, Project Report 77, Crowthorne, 1994.
Groner, R.: "Eye Movements, Attention and Visual Information Processing: Some Experimental Results and Metohdological Considerations"; in Lüer, G., Lass, U & Shallo- Hoffmana (eds.), "Eye Movement Research. Physiological and Psychological Aspects"; Toronto: J.P. Hogrefe, 1988.
Hagenzieker, M.P.: "Eye Movements in Traffic Research"; SWOW Institute for Road Safety Research, Leidschendam, 1992.
Hansen, J.P.: "Optagelser af visuelle orienteringer" ("Recordings of Visual Orientations"); Risø National Laboratory; DOPS-NYT, No. 2, 1990.
Hansen, J.P., Andersen, A.W. & Roed, P.: "Eye-Gaze Control of Multimedia Systems", Riso National Laboratory; paper presented at HCI International '95, Tokyo, 1995.
Luoma, J.: Perceptions and Eye Movements in Simulated Traffic Situations; in: Acta Ophthalmologica Suppl. 161, 1984 a.
Luoma, J.: "Driver's Visual Information Acquisition: The Interaction of Relevant and Irrelevant Information"; Liikenneturva, Helsinki, 1984 b.
Luoma, J.: "Drivers' Eye Fixation and Perception"; in Gale, A.G. et al. (eds.): "Vision in Vehicles - II"; Elsevier, North Holland, 1988.
Luoma, J.: "Perception of Highway Traffic Signs: Interaction of Eye Fixations, Recalls and Reactions"; Third International Conference on Vision in Vehicles, Aachen, Germany, 1989.
Zangenmeister, W.H.; Sherman, K. & Stark, L: "Evidence for a Global Strategy in Viewing Abstract Compared With Realistic Images"; Neuropsychologia, Oxford, 1995.
Theeuwes, J.: "Perceptual Selectivity is Task Dependant: Evidence from Selective Search"; Acta Psychologica 74, North Holland, 1990.
Theeuwes; J.: "Visual Selection, Exogenous and Endogenous control"; in Gale, A.G. et. al. (eds.). "Vision in Vehicles - III". Amsterdam, Elsevier, 1991.
Theeuwes: J.:Visuelles Orientierungsverhalten an Kreuzungen, in: Zeitschrift für Verkerhrssicherheit 41. 1995.

EFFECTS OF VARIABLE ROAD CONDITION SIGNS ON REPORTED DRIVER BEHAVIOR

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Abstract

A recent Finnish study by Rämä, Kulmala, and Heinonen (1996) showed that a variable sign warning about slippery road conditions reduced the mean speed by 1-2 km/h. The study showed also that a variable sign recommending a minimum headway between vehicles decreased by 28-38% the proportion of the drivers following other vehicles with headway of less than 1.5 seconds. However, the signs might have other effects on driver behavior in addition to the effects on speed and headway. Consequently, this study was designed to investigate other potential effects of these signs. The data were collected by telephone interviews involving car drivers willing to participate. The preceding roadside interviews sampled drivers who encountered either of the signs in adverse road surface conditions. Totally, 114 drivers that had encountered the slippery road sign and 111 drivers had encountered the minimum headway sign were interviewed. The questions about the slippery road sign concerned the prevailing road conditions (snow fall) and the slippery road conditions that are not easily detectable ('black ice'). The questions about the minimum headway sign concerned the prevailing 'black ice' conditions. The results suggested that these variable message signs have several other effects besides the measurable in terms of speed and headway. The most essential effects dealt with the direction of attention to find cues showing potential hazards, testing the slipperiness, and careful passing behavior. On the other hand, the results suggest that the driving speed and headway are essential variables with which many other variables correlate.

Introduction

Variable message signs (VMS) have been used for providing drivers with information, warning, or instruction. Along with the increasing use of variable message signs, research has been carried out in various aspects of their design and construction, message content, and effectiveness (TROPIC, 1996). This study concentrated on the effectiveness of particular variable warning signs.

A recent Finnish study by Rämä, Kulmala, and Heinonen (1996) showed that (a) the variable sign warning about slippery road conditions and (b) the variable sign recommending the minimum headway between vehicles (see Figure 1) had positive effects in terms of traffic safety. More specifically, the slippery road signs reduced the mean speed by 1-2 km/h and the minimum headway sign decreased by 28-38% the proportion of drivers following other vehicles with headway of less than 1.5 seconds. In addition, the minimum headway sign reduced the mean speed by 1 km/h.



(a) (b)

Figure 1. A schematic diagram showing (a) the slippery road sign and (b) the minimum headway sign. The messages displayed depend on the road surface condition classification by the road weather monitoring center: the slippery road sign is on or off and the minimum headway sign is always on, but the recommended minimum headway varies. In addition, the minimum headway depends on vehicle type and speed.

The signs might have other effects on driver behavior in addition to the effects on speed and headway. For example, drivers may focus their attention on road conditions or other vehicles, test the slipperiness, avoid passing, etc. These behavioral changes do not necessarily result in speed or headway changes, although the potential changes might be essential for impact evaluations. Consequently, this study was designed to investigate various potential effects of these signs.

Method

The data were collected by a combination of roadside and telephone interviews. The roadside interviews sampled drivers who encountered either of the signs shown in Figure 1 in adverse road surface conditions. Specifically, each roadside interview was conducted in January and February between 8 am and 1 pm while the signs were on and the measured coefficient of friction was between 0.2 and 0.3. Totally, 204 drivers that had encountered the slippery road sign and 181 drivers that had encountered the minimum headway sign were interviewed. Both interviewing sites were located on inter-urban highway. If a driver recalled and comprehended the sign in question, the interviewer requested whether he/she would be willing to participate in a telephone interview in the near future. The volunteers provided their phone numbers and a suitable date and time for the interview.

Telephone interviews were performed in two subsequent weeks. The questions about the slippery road sign concerned potential effects in the prevailing road conditions (snow fall) and the slippery road conditions that are not easily detectable ('black ice'). The questions about the minimum headway sign concerned the prevailing 'black ice' conditions. The telephone interviews included the following phases. First, the driver was asked: "What kind of effects did the *variable sign* have on your behavior, if any? Would it have any effects in other similar conditions?" Second, after listing all effects that he/she *spontaneously* liked to report, the interviewer presented a list of other potential effects (the effects on such behaviors as driving speed, setting of following distance, passing, lateral positioning of the vehicle, testing of the slipperiness, use of controls, performance of secondary tasks, monitoring weather forecasts, discussion of the sign, change of the driver, focusing of attention, driving comfort, change of the mode/interruption of the trip, or any other). Only items that were not reported spontaneously were asked. In addition, after each of these *main effects* that a driver indicated, the drivers were requested to provide some details. For example, the effect on driving speed (main effect) was an insufficient answer, while "speed reduction in general", "speed reduction in curves" were sufficient ones. This procedure resulted in relatively good covering of potential effects. However, it is assumed that the spontaneous responses are more reliable than the responses to given alternatives. Consequently, frequencies of both response categories are given separately.

In the case of drivers who had encountered the slippery road sign, the interview continued with a request to think road conditions in which the slipperiness would not be as detectable as at the moment of the roadside interview while the adverse conditions were also detectable without the sign ("Please think now weather and road conditions that would look good, but the sign would be on. What kind of effects the sign would have on your behavior, if any?"). This question was followed by the same procedure as in the case of the prevailing conditions. However, if a driver then reported spontaneously that the sign influenced so that he/she tested the slipperiness (and possibly some additional behaviors), the interview was interrupted. The reason for this was that the study was designed to investigate effects of the sign and not those of the sign and tested road conditions. On the other hand, it is acknowledged that the presented proportions of the effects may be somewhat biased because of this procedure.

Results

Drivers

Totally, 114 drivers that had encountered the slippery road sign and 111 drivers encountered the minimum headway sign were interviewed in the telephone interviews. Of the drivers participating in the roadside interviews, 36 did not recall or comprehend the sign, 46 were not willing to participate in the telephone interview, and 78 were not reached by phone.

Proportion of females was 14% for the slippery road sign and 26% for the minimum headway sign. Drivers' ages ranged from 23 to 75 years (with a mean of 43 years) for the slippery road sign and from 21 to 72 years (with a mean of 44 years) for the minimum headway sign. The distribution of the vehicle kilometrage during the previous year was the following (slippery road/headway): 16%/36% 15,000 km or less, 38%/39% 15,001-39,999 km, and 46%/25% 40,000 km or more.

Reported effects of the slippery road sign

Eleven percent of the drivers who had encountered the slippery road sign indicated that the sign had no effect on their behavior. The corresponding proportion in the 'black ice' conditions was 1%. Other drivers indicated the effects shown in Figure 2.

In both road conditions, the drivers reported that the slippery road sign influenced particularly driving speed. Specified effects included reduction of the driving speed in general and particularly in curves. (Only specified effects given more than 20% of the drivers in question are reported).

Another frequently reported effect was a change in the direction of attention. In both road conditions, drivers were more attentive than usually and monitored opposing vehicles. In the snow fall, drivers also reported concentration on own driving and in the 'black ice' conditions, drivers frequently reported monitoring road surface or vehicles traveling ahead.

Testing of the slipperiness was emphasized especially in the 'black ice' conditions. This almost always happened by braking. Furthermore, the drivers frequently reported the following responses: improved driving comfort, extended following distance, refraining from passing (completely, more cautiously, or more infrequently), and different use of controls (steering, brake pedal, or gas pedal).

Less frequently reported effects included discussion (of VMSs in general, the meaning of the message, or desired behavior), performance of secondary tasks (use of mobile phone or radio/cassette player), lateral positioning of the vehicle (driving closer to the edge line or avoiding slush that was reported only in the snow fall conditions), change of the driver (because he/she was tired or inexperienced), and monitoring weather forecasts (via radio).

No other effects were reported. For example, none of the drivers indicated that he/she would have changed the mode or interrupted the trip because of the slippery road sign.

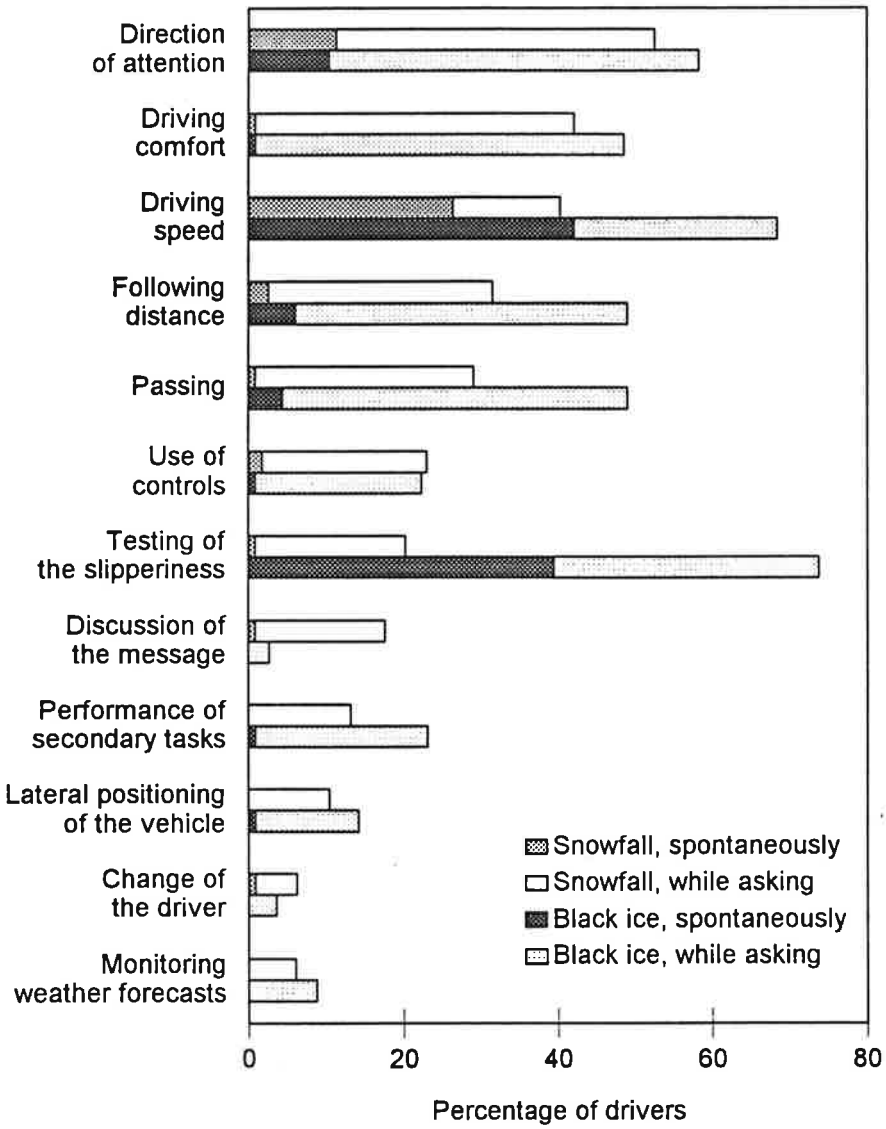


Figure 2. Reported effects of the slippery road sign by weather and road conditions.

Reported effects of the minimum headway sign

Two percent of the drivers who had encountered the minimum headway sign indicated that the sign had no effect on their behavior. Other drivers indicated the effects given in Figure 3.

The drivers indicated that the minimum headway sign particularly influenced the following distance (monitoring or increasing the distance). In addition, the following effects were reported relatively frequently: altered direction of attention (monitoring the vehicle ahead and focusing on own driving), discussion (of the meaning of the message, the appropriateness of the message, and the VMSs in general), driving speed (checking the actual speed and general reduction of speed), and testing of the slipperiness (by braking).

Less frequently reported effects included refraining from passing (completely, more cautiously, or more infrequently), (improved) driving comfort, secondary tasks (use of mobile phone, radio/cassette player), monitoring weather forecasts (via radio), and different use of controls (steering, brake pedal, or gas pedal),), change of the driver (because he/she was inexperienced), and lateral positioning of the vehicle (driving closer the edge line and avoiding slush). No other effects were reported.

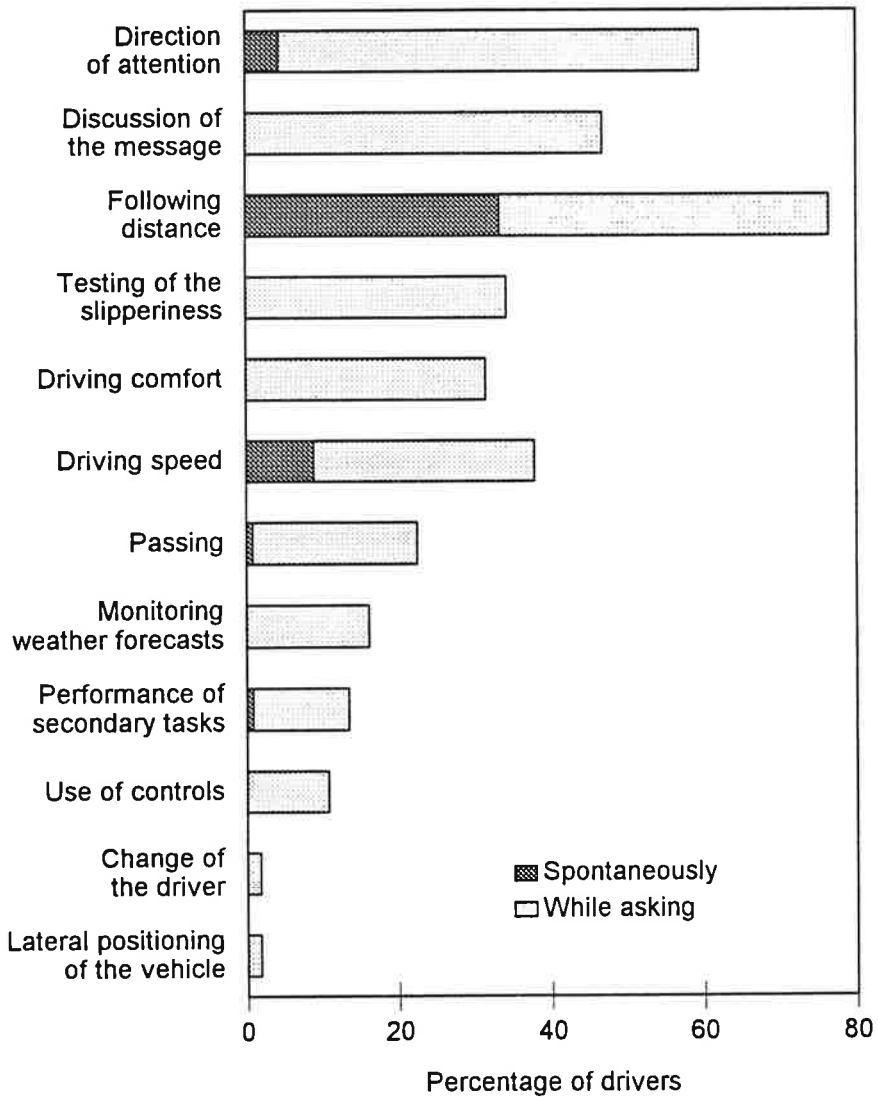


Figure 3. Reported effects of the minimum headway sign in 'black ice' conditions.

Correlations of the effects

This analysis focused on potential relationships between the effects of variable road condition signs on speed, following distance, and testing of slipperiness by themselves and with other effects. Results of crosstabulations are shown in Tables 1 and 2.

Table 1. Percentage of drivers who reported a given effect of the slippery road sign by reporting effects on driving speed, following distance, and testing of slipperiness. Statistically significant ($p < .05$) differences are bolded.

Behavior	Weather and road conditions	Driving speed		Following distance		Testing of the slipperiness	
		yes, %	no, %	yes, %	no, %	yes, %	no, %
Driving speed	Snow fall			**56**	**33**	39	41
	'Black ice'			**91**	**47**		
Following distance	Snow fall	**44**	**24**			48	28
	'Black ice'	**65**	**14**				
Testing of slipperiness	Snow fall	20	21	31	15		
	'Black ice'						
Passing	Snow fall	**52**	**13**	**53**	**18**	39	26
	'Black ice'	**65**	**14**	**82**	**17**		
Lateral positioning of the vehicle	Snow fall	**17**	**6**	11	17	**22**	7
	'Black ice'	**21**	**0**	**21**	7		
Use of controls	Snow fall	**39**	**12**	31	19	35	20
	'Black ice'	**32**	**0**	**32**	**12**		
Secondary tasks	Snow fall	20	9	**33**	**4**	**30**	**8**
	'Black ice'	**31**	**6**	**38**	**9**		
Monitoring weather forecasts	Snow fall	4	7	6	6	**17**	**3**
	'Black ice'	**13**	**0**	**18**	**0**		
Discussion of the sign	Snow fall	20	16	18	17	13	19
	'Black ice'	4	0	4	2		
Change of the driver	Snow fall	2	9	6	11	4	7
	'Black ice'	22	8	27	9		
Direction of attention	Snow fall	**72**	**40**	64	47	**74**	**47**
	'Black ice'	**72**	**28**	**88**	**29**		
Driving comfort	Snow fall	48	38	50	39	48	41
	'Black ice'	**55**	**33**	**70**	**28**		

First, the results showed that the effects of the slippery road sign on speed and the following distance correlated positively with each other. The relationship of these variables with the testing of the slipperiness was not so evident. Second, if a driver indicated that the sign influenced driving speed, following distance, or testing of slipperiness, then he/she more frequently reported other effects. Each of the statistically significant differences supported this pattern.

The results given in Table 2 showed rather similar trends for the minimum headway sign. However, the relationships were not as strong.

Table 2. Percentage of drivers who reported a given effect of the minimum headway sign by reporting effects on driving speed, following distance, and testing of slipperiness. Statistically significant ($p < .05$) differences are bolded.

Behavior	Driving speed		Following distance		Testing of the slipperiness	
	yes, %	no, %	yes, %	no, %	yes, %	no, %
Driving speed			41	27	42	36
Following distance	83	73			82	74
Testing of slipperiness	38	32	37	27		
Passing	**33**	**16**	26	12	16	26
Lateral positioning of the vehicle	2	1	2	0	3	1
Use of controls	17	7	12	8	13	10
Secondary tasks	21	9	15	8	13	14
Monitoring weather forecasts	10	20	19	8	18	15
Discussion of the sign	50	45	49	39	47	47
Change of the driver	5	0	2	0	3	1
Direction of attention	**79**	**48**	62	50	63	58
Driving comfort	31	32	77	23	37	29

Effects by driver group

Main effects (e.g., effects on driving speed, etc.) were analyzed by gender, age and driving experience during the preceding year. The results showed that there were no statistically significant ($p < .05$) differences, except for the following ones:

- The percentage of drivers that indicated effects of the slippery road sign on testing the slipperiness in snow fall conditions increased together with increasing driving experience during the preceding year (6% - 14% - 31%, experience categories as indicated earlier).
- Effects of the slippery road sign on the use of controls in the 'black ice' conditions' varied by driving experience during the preceding year (11% - 34% - 16%).
- In the snow fall conditions, female drivers indicated more frequently than male drivers that the slippery road sign influenced the use of controls (44% vs. 19%).
- Effects of the minimum headway sign on following distance decreased, while the driving experience during the preceding year increased (92% - 89% - 68%).
- Male drivers indicated more frequently than female drivers that the minimum headway sign influenced driving comfort (48% vs. 26%).

Discussion

The results suggested that the variable message signs have several other effects besides those that can be measured in terms of speed and headway. Only 1-11% of the interviewed drivers indicated that the sign had no effect on behavior. The most fundamental effects - in addition to the effects on driving speed and headway - dealt with the direction of attention to find cues showing potential hazards, testing the slipperiness, and careful passing behavior. The slippery road sign had more effects in the 'black ice' conditions than in the snow fall conditions, on average.

Most of the reported effects can be assessed as positive in terms of traffic safety. Thus, the drivers - according to their reports - seem to behave rather adequately while encountering the variable slippery road signs or minimum headway signs. In addition, many drivers indicated that the driving comfort was improved.

Moreover, the results suggested that the driving speed and headway were also among the most frequently reported effects with which many other variables correlated. This finding has three implications. First, the previous studies (e.g., Rämä *et al.*, 1996; Rämä, 1997) investigating effects of variable road condition signs have focused on essential variables. Second, if such investigations show that a sign has positive effects on speed behavior and following distance, it is likely to have also other positive effects on driver behavior. Consequently, the investigation of effects on speed and following distance is recommended, because the measuring of these effects is less time consuming, more reliable, and less expensive than the investigation of other effects. Third, this finding suggests that the reduction of driving speed does not have harmful side effects, such as decreased level of attention, as sometimes has been argued.

The results showed that the effects of the signs were general in nature rather than evident only for certain driver groups. This finding is desirable, because the variable road condition signs are meant to provide information for all drivers.

While assessing the reliability of the results, it is useful take into account that there were two types of responses: spontaneous responses and those that were replies to a particular question. It is assumed that the spontaneous answers were relatively reliable, but other answers may include additional effects, because some drivers might have a tendency to please the interviewer by attempting to report several effects. However, a potential bias may not be substantial, because the interviewer did not give any sign indicating that a great number of effects would be desirable.

Another factor influencing the reliability is the easiness to assess a given effect. We may assume that the easiness of assessment varied and the easiness increased the reliability of answer. For example, the easy effects might include such as speed behavior, testing of slipperiness, monitoring weather forecast, while direction of attention or change of driving comfort might be more difficult to assess.

The reliability of the results can also be assessed by comparing the reported effects on speed and following distance with the results of earlier studies involving objective measurements. However, the results of Rämä *et al.* (1996) showed the effects in terms of km/h and m, while the drivers of the present study were not able to indicate the magnitude of the effects. Nevertheless, the same trends were evident.

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References

Rämä, P. (1997). Effects of weather controlled traffic management system on driver behaviour. *Proceedings of the 4th World Congress on Intelligent Transport Systems, Berlin, October 21-24, 1997,* in press.

Rämä, P., Kulmala, R. and Heinonen, M. (1996). *Muuttuvien kelivaroitusmerkkien vaikutus ajonopeuksiin, aikaväleihin ja kuljettajien käsityksiin* [The effect of variable road condition warning signs]. Helsinki: Finnish National Road Administration, Finnra Reports 1/1996.

TROPIC (1996). Research review report, Traffic optimisation by the integration of information and control, feasibility study. Birmingham: Atkins Wootton Jeffreys.

A Driving Simulator Test of an Alertness Device

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Abstract

A simulator study investigated whether drivers' alertness, in drowsiness inducing conditions, can be maintained by a game-like system, a gamebox. Drowsiness was assessed by self-rating, blinking rate and eye closures. Mental effort was assessed by the NASA-TLX scale and by a physiological measure - the 0.1 Hz component of heart rate. Driving quality and safety were assessed by lane position and steering movements, a TLC (time-to-line crossing) measure, and by the occurrence of safety related driving errors - solid line crossings, driving off the pavement incidents and accidents.

When driving with the game device, drivers reported lower degrees of drowsiness and fewer instances of sleep episodes. Eye closures were in agreement with the subjective reports by drivers. Compared to a control condition, driving with the device resulted in fewer accidents and incidents and these occurred later in the session. The quality of vehicle control deteriorated over the course of the session, but less so in the gamebox condition. The gamebox benefited to some extent all drivers, but more so drivers who generally considered themselves very susceptible to drowsiness.

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Introduction

Drowsiness and traffic accidents

There is a broad consensus that the conditions associated with drowsiness accidents are long hours of driving in monotonous road conditions and when driving interferes with regular hours of sleep and, therefore, fatigue and drowsiness accidents typically occur during late night hours and on inter-urban roads. Estimates of fatigue, sleepiness, or drowsiness involvement in accidents range from 1% to 4% involvement rate estimated from general police databases to 10 - 25% or even higher when based on "in-depth" accident investigations or on clinical studies (Horne and Reyner 1995).

Drivers' experience with drowsiness

Drivers are usually quite aware of their drowsiness state and many have experienced driving in that condition. They can also recall instances of falling asleep behind the wheel.

In the UK, a national survey of car drivers (Maycock 1995) revealed that 29% of them have had at least one experience of a serious drowsiness episode during the last year. About ten percent reported on having been involved, due to drowsiness, in an accident in the last three years, mostly at night and on inter-urban roads. Essentially similar results were reported by McCartt *et al.* , (1995), based on a survey of drivers in New York state.

While drivers are generally aware of becoming drowsy, their ability to accurately monitor progressive, or momentary, shifts in their condition is often limited (e.g., Seko, Kataoka, and Senoo 1995, Skipper and Wierwille 1986, Wylie *et al.* 1996). Most commonly, drivers' own assessment of the decline in their alertness was found to lag behind objective indicators of drowsiness. The implication of this bias is that drivers might not invest sufficient effort in staying alert, or they over-estimate the success of their efforts and, therefore, continue driving beyond their capabilities.

The nature of alerting devices

In-vehicle alerting devices to counteract driver drowsiness can be divided into two general categories. The first includes those designed for detection of drowsiness followed by a warning and, in more advanced concepts, followed by intervention. In the second category are devices which are designed for maintaining alertness by some form of activation of the driver throughout the trip. This approach can be traced to interpretation of drowsiness as reflecting, in part, lowered arousal due to lack of stimulation. Accordingly, it was hoped that the drowsiness condition might be counteracted by presenting operators with additional stimulation.

In the context of driving research, the presence of an additional task is usually considered a "secondary task" (or "subsidiary task") which is presumed to "load" drivers and perhaps even create a task "over-load" situation. It is employed for two purposes: (a) to load drivers in order to measure their remaining attention or processing capacity in various driving situations (e.g., Verwey and Veltman 1996) and, (b) to investigate the effect of the subsidiary activity itself, such as the use of a cellular phone or listening to traffic information, on the quality of driving (e.g., Verwey 1996).

However, monotonous driving, especially at night and on rural roads, is a situation better described as an "under-load" situation with, possibly, lower arousal due to drowsiness or predictive stimulation (Wertheim 1991). Here, an attention demanding "secondary task" might increase the general level of arousal and improve performance. More generally, activities additional to driving might be detrimental in busy driving situations but beneficial when driving in under-load situations.

Wierwille *et al.* (1994) found that a secondary task requiring a simple yes / no response every 15 seconds tended to reduce drowsiness and to improve vehicle control measures. The findings were tentative due to a small number of drivers and the rather demanding schedule of the task. Fairbanks, Fahey and Wierwille (1995) report on further testing of secondary task stimuli as an alertness maintenance device (after drowsiness was detected), with generally disappointing results.

Everyday evidence for the use of additional tasks to maintain driver alertness comes from anecdotal evidence and driver survey data (e.g., Maycock 1995, McBain 1970) which suggest that drivers engage in a variety of self-initiated activities in order to maintain alertness. Very common are the use of radio, pre-recorded media, and conversing with passengers - if present. Some drivers prefer talk programs or educational programs over music because such programs are more interesting, more mentally challenging, or give them a better sense of "a person talking to them". With the spread of cellular phones (or CB radio in some countries) many drivers find it helpful (and useful) to communicate with other people on the road or elsewhere. Other drivers engage in mental games or exercises to keep alert and pass the time. For example, simple counting and calculating games, creating lists of words by certain rules, solving anagrams, or interacting with a language teaching program on tape. There is practically no research on the effectiveness of drivers' own methods for alertness maintaining, and whether the methods could be optimized and taught to others.

The purpose of the study

The purpose of the present study was to examine whether mental activity encouraged by a game-like task, during a monotonous long drive, could reduce degradation of safe driving performance caused by drowsiness and fatigue. It was our conviction that in order to avoid interference with driving and to be motivating, the mental task had to be interesting, self paced, used at will, and not overly difficult. Drivers should be able to adapt the complexity of the task to their abilities and to the demands of the driving task. To reduce interference with driving, the task should not overly involve the visual channel or interfere with hand operation (Verwey 1996).

The additional task in the present study was incorporated in a gamebox which contained twelve activities (i.e., games) varying in type, complexity and potential challenge. Activities could be selected and initiated at will and interaction between the driver and the device was via speech.

The hypothesized effect of the gamebox on driving performance could be due to a reduction in drowsiness and a generally increased level of alertness; or it could be an indirect product of drivers being motivated to invest more effort in keeping a safe level of performance. To investigate this issue, effort investment was assessed with both subjective and physiological measures.

METHOD

An overview of the experiment

Twenty six drivers drove a monotonous rural road for 2 hours and 15 min in a fixed-base driving simulator. They were pre-selected to have either a high or low tendency to get drowsy during long trips at night. Each driver drove the route twice, about four to seven days apart, during one of three different night shifts while not having slept before the drive. In a control condition, drivers had to just drive the route. In an alertness-aided condition, drivers were provided with an "alertness maintenance device" (a gamebox) with which they could interact at will.

The experimental design is a mixed, repeated measures design on 2 aiding conditions, and a 3 x 2 factorial on shift and driver type. Order of repetition was counter-balanced across all other conditions. Time-on-task was added as an independent variable to some analyses.

A data acquisition system collected a video record of drivers' face and eyes, various physiological measures, and selected vehicle performance measures. From these it was possible to determine the progression of drowsiness over time, the frequency of serious driving incidents and their behavioral precursors, and the effect that the gamebox had on drowsiness and quality of driving.

Participants

Drivers were selected on the basis of a telephone screening interview. Their age range was 25 to 49 years, (mean of each group: 38). They had their license for at least five years (average 17 years). There were 12 female and 14 male drivers. None used medication that could affect driving performance. Drivers were paid for their participation. They were promised a bonus for safe driving which, in practice, everybody received.

Dependent variables.

The main dependent variables were driving performance measures, driver drowsiness measures - blinking, eye closure, and self-rating of sleepiness on a 7-key scale every 25-35 min.-, driver mental effort, and the extent of using the gamebox.

Subjective mental workload was assessed with the NASA-TLX scale (Hart, S.G. and Staveland, L.E. 1988). The physiological measure of mental effort was the 0.1 Hz component of the heart rate variability (Mulder 1980). This measure has been frequently used to assess effort in cognitively demanding tasks where it was suspected that operators might be overloaded but some studies also assessed underload situations (e.g., Egelund 1982). The application here is to indicate mental effort in an underload situation where sleepiness must be resisted..

Apparatus and scenario

The experiment took place in a fixed base driving simulator at the TNO Human Factors Research Institute. The road was a two lane, 7.2 m wide road where the legal speed limit is 80 kph. The road curved gently through a flat rural landscape and day sight-distance was generally 800 m. Scenery was similar throughout the drive and included road markings,

kilometer posts (with no numbers), scattered trees and shrubs and some outline of topographical features. Light conditions simulated an early dawn and vehicles had their lights on. The scenario embedded some situations and traffic events which require more attention from drivers: sharp curves; oncoming cars; parked cars; and slow moving vehicles;

Procedure

On the night of participating in the study, drivers had a regular day of activity without having any sleep before arriving to the laboratory. Coffee and alcohol were not allowed after 18:00. Upon arrival, hours before their driving time, they filled out consent forms and questionnaires and waited in a special area, provided with beverages, light snacks, magazines and audio-visual media.

After being fitted with the physiological sensors, participants were instructed about the use of the simulator car, the location and use of the alertness rating box, and the nature of the task. They were asked to drive safely in the way they would normally do. At the conclusion of the driving session, each driver filled out a post-drive questionnaire and was taken home by taxi.

RESULTS

Drowsiness measures

Has the gamebox affected subjective drowsiness and effort?

In- vehicle ratings (Figure 1) shows that on a scale from 0 (fully alert) to 6 (very sleepy), drowsiness increased monotonically with time-on-task [$F(4,72)=60.4$, $p<.001$]. The analysis also confirmed the success of the experimental manipulation of task difficulty and of the two types of drivers (the detailed analyses of these variables are reported elsewhere).

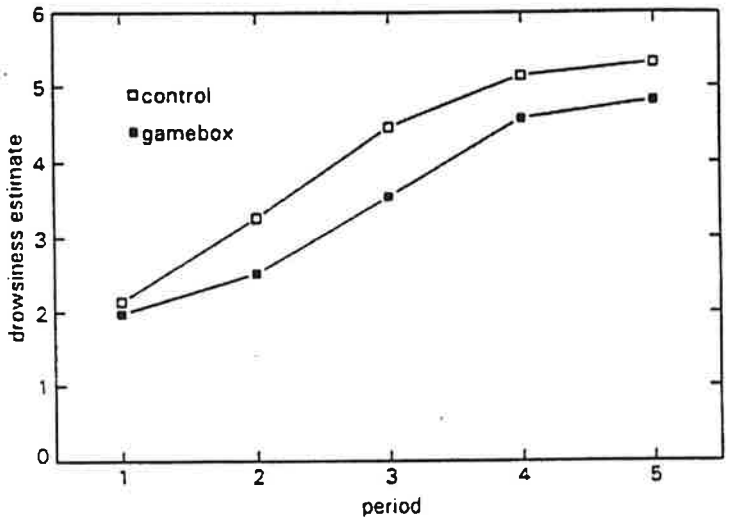


Fig.1 Selfreported drowsiness during the session.

Drivers thought they had actually fallen asleep 4.7 times, on the average, in the control condition and 1.0 time in the gamebox condition [$\chi^2(1) = 59.7$, $p<.001$]. Falling asleep was experienced by 17 out of 25 drivers in the control condition and by 9 out of 25 drivers in the gamebox condition, [$\chi^2(1) = 5.1$, $p<.05$].

TLX ratings given immediately after the drive with respect to the early and the last part of the drive, showed a significant early / late effect and a shift effect. Gamebox / control conditions did not differ significantly.

The physiological indicator of effort (the 0.10 Hz component of the heart rate signal) was also sensitive to time-on-task - effort went down with time [$F(8,72)=3.07$, $p<.01$] - but did not distinguish between control and gamebox conditions.

Has the gamebox affected blinking and eye closures?

We observed several instances of very obvious sleepiness as expressed in yawning, frequent blinking, drooping face, blank staring, long eye closures, head nodding, and other symptoms of drowsiness and the effort to fight it off. For quantitative analysis we used only blinking and longer eye closures as indicators of drowsiness.

A loglinear analysis of eye blink frequency (summed across drivers and excluding closures longer than 1 s) showed that more blinks occurred in the gamebox condition than in the control condition [frequencies per driver per 3 min period: gamebox: 64.6, control: 58.4; $\chi^2(1) = 41.0$, $p<.001$]. Long eye closures (i.e., > 1 s) did not occur in the first three min periods. A log-linear analysis on closure frequencies in the late period showed more closures in the control than in the gamebox condition [frequencies per driver per 3 min period: control: 2.1, gamebox: 1.3; $\chi^2(1) = 4.6$, $p<.05$].

The data suggest that the experimental manipulations were successful in inducing drowsiness. The frequency of long eye closures appears to be the most reliable indicator of driver drowsiness. It is not that blinking is not affected by drowsiness but that the changes in blinking are more complex. For example, Seko, Kataoka, and Senoo (1995) present records of blinks, in drowsy drivers, which change in duration, frequency and regularity. Episodes of long closures as well as long staring with no blinking, complicate the pattern even more.

Has the gamebox averted driving errors?

This section will discuss three types of errors. First, *accidents* are those events in which the vehicle left the road (i.e., the asphalt) entirely. Second, *incidents* entail all events in which the vehicle left the road with two wheels, and, third, *crossing events* are those events in which solid lane edge marks (left and right) were crossed but the road was not left. Care was taken not to double-count events.

These observable events were counted automatically from the vehicle performance data in the simulator, and their exact location registered. Analyses of all data records (including ratings, heart rate, and blinks reported earlier) were halted at the accident location. Visual inspection of the video records confirmed that in most cases, performance following an accident only got worse, indicating that the accidents had indeed been caused by extreme levels of drowsiness.

Table 1 presents the occurrence and timing of accidents, incidents, and crossing events in the two conditions, and the proportion of drivers involved in these unsafe events.

Table 1 Accidents, incidents, and crossing events in two conditions.

measure	control	gamebox
no. of drivers with an accident	6 (23%)	2 (8%)
mean time to accident	87 min.	103 min.
no. of drivers with an incident	10 (38%)	7 (28%)
mean number of incidents per incident-driver	4.6	3.0
mean time to first incident	83 min.	94 min.
no. of drivers with crossing events	10 (40%)	6 (24%)
mean number of crossing events per driver	3.9	3.7
mean time to first crossing	64 min.	79 min.
number of drivers with any event	15 (58%)	8 (32%)
total number of events	81	45
mean number of events across all drivers	3.2	1.8

Table 1 clearly shows that there is an advantage for the gamebox condition on all measures of driver errors. Compared to the control condition, fewer drivers in the gamebox condition ended up with an accident, incidents, and solid line crossings and it took longer for the first of these events to occur. The control condition had about twice as many incidents and crossings than the gamebox condition. All accident events took place in the second half of the driving session. The frequency of incidents and crossing events was higher in the later periods of the drive.

While some of the differences appear small, they are all very consistent, and by and large statistically significant. It should be noted that events were not equally distributed amongst drivers. A total of 14 drivers had accidents or incidents; 12 drivers had none.
This pattern of results suggests a performance degradation process in which increased drowsiness generates more crossing errors which lead into more serious incidents and, eventually, to an accident.

DISCUSSION

The results clearly demonstrate that the gamebox counteracted the normal performance deterioration in driving which is typical for monotonous driving. It reduced the numbers of accident, incidents and crossing events and it delayed the onset of errors. The positive impact on performance measures is supported by the effects on the various indicators for drowsiness - subjective reports of drowsiness and of sleep episodes during and after the drive, and longer eye closures.

The fact that the mental activity associated with interacting with the gamebox counteracted performance deterioration, suggests that the lack of attentional resources in normal monotonous driving is caused by a lack of mental activity - after all lane keeping is a largely automatic task. This notion is confirmed by Lisper *et al.*'s (1986) finding that inexperienced drivers, for whom lane keeping is probably less automated (Verwey, 1993), had less difficulty in staying awake than experienced drivers in the same condition.

Subjective effort ratings increased with time-on-task while the 0.1 Hz component suggested a reduction in effort. This divergence, between subjective measures of effort and the 0.1 Hz component, suggests that the 0.1 Hz measure here reflects the actual drowsiness state while subjective effort is a measure of "doing one's best" to maintain performance at an acceptable level. In studies with high workload, physiological state is probably affected directly by doing one's best, and consequently the physiological and subjective effort measures are similar. But, as our data suggest, in underload conditions where the natural tendency to become drowsy is strong, a divergence between the two effort indicators can occur.

Even drivers who did not commit serious errors exhibited increased drowsiness and degraded performance as a function of time on task or shift. Their reduced performance, however, stayed within safety bounds. It is quite possible that longer periods of driving or other fatiguing factors would push their performance out of bounds too. Some drivers, by virtue of their personality, constitution, or experience, are likely more than others to succumb to drowsiness, and are less able to fight off its effects. They are aware of this tendency and are willing, even eager, to make use of procedures and devices which promise a reduction in drowsiness.

Many drivers reported finding the device helpful and supported the concept of the device. The device, despite its technical limitations, benefited to some extent all drivers, and even more so those drivers who needed the help most. The device was utilized in different ways by different drivers. Some hardly turned it on; some interacted with it during a large part of the session; most operated it occasionally, for various periods of times. Sometimes drivers used it while still appearing (and self-rating themselves) quite alert; at other times they activated it when they felt very drowsy.

Many driving situations induce loss of alertness and could benefit from using the alerting concept. Actual design issues such as the nature of mental activities, the interface with drivers and possibly connection with detection systems, need to be investigated before optimal devices can be developed.

REFERENCES

Egelund, N. (1982). Spectral analysis of heart rate variability as an indicator of driver fatigue. Ergonomics, 25, 663-672.

Fairbanks, R.J., Fahey, S.E., and Wierwille, W.W. (1995). Research on vehicle based driver status/performance monitoring: seventh semi-annual research report. Report DOT HS 808 299, NTIS, Springfield, VA 22161.

Hart, S.G., and Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P.A. Hancock and N. Meshkati (Eds.), Human Mental Workload (pp. 139-183). Amsterdam: North-Holland.

Horne, J.A., and Reyner, L.A. (1995). Falling asleep at the wheel. TRL Report 168. Crowthorne, UK: Transport Research Laboratory.

Lisper, H.-O., Laurell, H., and Van Loon, J. (1986). Relation between time to falling asleep behind the wheel on a closed track and changes in subsidiary reaction time during prolonged driving on a motorway. Ergonomics, 29, 445-453.

Maycock, G. (1995). Driver sleepiness as a factor in car and HGV accidents. (Technical report 169). Crowthorne, UK: Transport and Research Laboratory.

McBain, W.N. (1970). Arousal, monotony, and accidents in line driving. Journal of Applied Psychology, 54, 509-519.

McCartt, A.T., Ribner, S.A., Pack, A.I., and Hammer, M.C. (1995). The scope and nature of the drowsy driving problem in New York state: 39th Annual Proceedings of the Association for the Advancement of Automotive Medicine. Chicago, Illinois.

Mulder, G. (1980). The heart of mental effort. Thesis. Groningen: University of Groningen.

Seko, Y., Kataoka, S., and Senoo, T. (1995). Analysis of driving behaviour under a state of reduced alertness: JSAE Review, April, 66-72.

Skipper, J.H., and Wierwille, W.W. (1986). An investigation of low-level stimulus-induced measures of driver drowsiness. In A.G. Gale et al. (Eds.), Vision in Vehicles (pp.139-148). Amsterdam: North Holland.

Verwey, W.B. (1993). How can we prevent overload of the driver? In A.M. Parkes and S. Franzén (Eds.), Driving future vehicles (pp.235-244). London: Taylor and Francis.

Verwey, W.B. (1996). Evaluating safety effects of in-vehicle information systems. A field experiment with traffic congestion systems (RDS-TMC) and preliminary guidelines for IVIS. (Report TM 96-C068). Soesterberg, the Netherlands: TNO Human Factors Research Institute.

Verwey, W.B., and Veltman, J.A. (1996). Detecting short periods of elevated workload. A comparison of nine workload assessment techniques. Journal of Experimental Psychology: Applied, 2, 270-285.

Wertheim, A.H. (1991). Highway hypnosis: A theoretical analysis. In: A.G. Gale, I.D. Brown, C.M. Haslegrave, I. Moorhead, and S. Taylor (Eds.), Vision in Vehicles III (pp. 467-472). Amsterdam: North-Holland.

Wierwille, W.W., Ellsworth, L.A., Wreggit, S.S., Fairbanks, R.J., and Kirn, C.L. (1994). Research on vehicle based driver status/performance monitoring: development, validation, and refinement of algorithms for detection of driver drowsiness. Report DOT HS 808 247, NTIS, Springfield, VA 22161.

Wylie, C.D., Shultz, T., Miller, J.C., Mitler, M.M., and Mackie, R.R. (1996). Commercial motor vehicle driver fatigue study: technical summary. Report FHWA-MC-97-001, NTIS, Springfield, VA 22161.

3. BEHAVIOURAL AND CONFLICT EVALUATION

Chairperson: Nicole Muhlrad

• **UK Work on Automatic Speed Control.** CARSTEN Oliver, COMTE Samantha, Institute for Transport Studies, University of Leeds, UK

• **The effects of speed limiter in cars.** ALMQVIST Sverker, VARHELYI András, HYDÉN Christer, Dept of Traffic Planning and Engineering, Lund, Sweden

• **Initial Experience with Traffic Conflict Techniques in Brazil.** PIRES GUEDES Erivelton, BRAGA Marilita, COPPE/Univ of Rio de Janeiro. PIETRANTONIO Hugo, Polytechnic School, Univ of Sao Paolo, Brazil

• **Safety Evaluation of Ramp Metering In Glasgow, Scotland.** BRADER Colin, Atkins Wootton Jeffreys, Birgmingham. McLEAN Tom, Glasgow City Council, UK

• **Deceleration to Safety Time (DST) – a useful figure to evaluate traffic safety?** HUPFER Christoph, GVA Gesellschaft für Verkehrs-Analyse, Kaiserslautern, Germany

• **Study of Traffic Accident Mechanism by Automatic Recording System (TAAMS).** UEYAMA Masaru, National Research Institute of Police Science, Japan

• **Traffic analysis with image processing.** ODELID Klas, ANDERSSON Jörgen, Dept of Traffic Planning and Engineering, Lund, Sweden

• **Psychological Aspects of Accidents in Area of Road-Railway Grade Crossings.** ROTTER Tadeusz, Jagiellonian University, Cracow, Poland

• **The effect of driving speed on subjective safety evaluation.** ZAKOWSKA Lidia, Cracow Univ. of Technology, Cracow, Poland

UK Work on Automatic Speed Control

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1 Introduction

In the UK, there has been quite extensive discussion of the potential benefits of automatic speed control of vehicle, to the extent even of one book on the subject (Plowden and Hillman, 1996). Plowden and Hillman suggest that "the adoption of lower speed limits, enforced by variable speed limiters, will save lives and make our towns safer for all road users, especially children and old people. It will also reduce pollution and fuel consumption, weaken still further the case for major new roads, and minimise the need for police involvement in enforcement. Speed control is an immensely powerful instrument of transport policy which has so far been little exploited." There has, however, until recently been comparatively real research on such a system. This paper reports on the results of one completed research project, funded by the UK Engineering and Physical Sciences Research Council (EPSRC) as well as on the work which has started for a new research project, funded by the Department of Environment Transport and the Regions (DETR), formerly Department of Transport.

2 Aims of the Research

As already indicated, there has been virtually no empirical investigation of how British drivers would behave in cars whose maximum speed was controlled to the legal speed limit and perhaps additionally to prevailing traffic and road conditions. There had also been comparatively little study of what might occur when, because of the gradual process before the system became pervasive, only part of the vehicle fleet was equipped. Therefore the objectives of the EPSRC-funded project "Response to Automatic Speed Control in Urban Areas", completed in 1996, were:

- To predict the safety benefits of systems that would automatically control maximum vehicle speed in urban areas.
- To identify undesirable side effects of such systems resulting from behavioural adaptation (risk compensation) or from drivers having difficulty in adjusting to the system.
- To identify whether problems might occur if not all vehicles are equipped.

3 Method

The investigation was conducted on the University of Leeds Advanced Driving Simulator (Carsten and Gallimore, 1993). This facility is a sophisticated, static-base simulator where the

"driver" sits in a complete car, with all the basic controls and dashboard indicators fully operational. Using a complex vehicle handling model and sophisticated visualisation software, animated images of the scene are projected around the driver in real time. At the time of this project, there was only a single projector providing a 60° field of view to the front. Other traffic can be programmed into the scene. The road layout, the general scene, the vehicle dynamics model and the behaviour of the other traffic can all be constructed "to order", providing an ideal facility for testing new systems and new concepts, such as speed control. Major advantages of a simulator for investigating systems such as automatic speed control are the comparatively low cost of modifying the vehicle behaviour, the capability to investigate risky situations and the assurance that all the subjects have driven the identical road in the identical traffic conditions.

The speed limiter was implemented by altering the vehicle dynamics model. When operational the speed limiter prevented the driver from exceeding the legal external speed limit (here 30 mph) on the roads within an urban area. In addition, a limited amount of braking (a maximum of 10 bar) was applied to the vehicle as it entered the 30 mph zone, if the subjects did not slow down enough of their own accord. A road network was simulated incorporating junctions and links into an urban scene. The general hypothesis was that the subjects would engage in more aggressive driving when they were speed controlled, and that this more aggressive driving style would be exemplified by the acceptance of smaller gaps, by a greater propensity to red-light violation and by shorter headways in car following.

Therefore the route was built to allow investigation of these behaviours. At a number of points on the route, the subjects had to make right-turning manoeuvres across oncoming traffic, after being forced to come to a complete stop. They thus had to carry out a gap acceptance task. In addition to speed, car following behaviour and traffic light violations were recorded. For the car following, the drivers were deliberately subjected to a slow moving car in front, and the traffic signals were in some cases changed to red just as the drivers approached a junction. The scenarios under investigation were incorporated into a continuous road network, allowing natural movement from one scenario to the next. At the end of each run, the drivers' mental workload was assessed using the NASA RTLX adapted from Byers et al. (1989).

Thirty subjects completed the experiment. The sample included 15 males between the ages of 23 and 54 (mean age: 37 years) with a reported annual mileage of between 7,000 and 40,000 miles (mean = 17,600 miles); and 15 females between the ages of 24 and 49 (mean age: 37 years) with a reported annual mileage of between 6,000 and 25,000 miles (mean = 15,200 miles).

Subjects encountered all of the following four conditions is successive trials.

NSL/NSL	This was the control condition. Neither the subject's car nor any of the other cars on the road were fitted with a speed limiter.
NSL/50SL	This condition represented the 'mixed-fleet' scenario. The subject's car was not fitted with a speed limiter but approximately 50% of the other cars on the road had one.
SL/SL	Here the full implementation stage was reached. Both the subject's car and all the other cars on the road were fitted with a speed limiter.
SL+/SL+	Both the simulator and all the other cars on the road have been fitted with a speed limiter. In addition, a secondary implementation of the speed limiter is also present in all cars. This secondary speed limiter automatically slowed the cars to a maximum of 25 mph around the vicinity of junctions.

The order of the trials was balanced across subjects.

4 Results

Where appropriate the data were analysed with multi-factorial analysis (ANOVA), with one within subjects factor (System) and two between subjects factors (Age and Sex). There were no statistically significant differences between the two speed limited conditions (full implementation and secondary limiter) nor between the two non-speed limited conditions (control and 50% implementation). Therefore the rest of the discussion refers only to differences between the combined conditions of System On and System Off.

4.1 Approach to junctions

A significant main effect of System was found ($F(3,87)= 50.87$; $p<.001$) indicating that the speed limiter condition produced lower average approach speeds (mean = 22.42 mph) than the non-speed limited condition (mean = 24.08 mph). However post-hoc analyses (Tukey's HSD) subsequently revealed that this reduction in speed is statistically reliable only in the approach sections between 80–31 metres from the junction. So although speeds were lower on approach when drivers were speed limited, they were very similar for the main deceleration profile on the immediate approach to the junction. A significant main effect of Age ($F(1,29)= 47.96$;$p <. 001$) indicating that those subjects under the age of 35 overall drove faster than those over the age of 35, is accompanied by a significant interaction between System and Age indicating that the effect of the System is not consistent across Age groups: the higher speeds for younger drivers were not observable in the condition in which they are speed limited.

4.2 Speed on curves

There were no effects of System on speeds at curve entry, curve apex or curve exit. However, there was an effect on speed variance over the whole curve such that speed variance was lower when the subjects were speed limited. Variance was reduced from 1.28 mph to 0.63 mph ($F(3,87)= 3.29$;$p <. 05$).

4.3 Traffic light violations

A chi-square test for independence revealed a significant difference in the number of traffic light violations committed (χ^2= 4.358, df=1, p<0.05). When drivers were speed limited, they tended to commit fewer traffic light violations.

4.4 Car following

For each subject, the percentage of headway time occupied in each half second unit between 0–6 seconds was calculated. A mean percentage was then derived across subjects in each condition. With the speed limiter, there was reduced positive skewness in the distribution, i.e. following behaviour became safer by there being less tendency to adopt short headways.

4.5 Gap acceptance

A value for the mean gap accepted in turning manoeuvres across on-coming traffic was calculated for each condition. There was a main effect of System on size of gap accepted, (F(3,87)= 6.23, p<0.01). Subjects accepted smaller gaps when they were speed limited (mean = 46.69) than when they were not speed limited (mean = 54.15). There was also a significant main effect of Sex such that males (mean = 47.25) accepted smaller gaps than females (mean = 52.25).

4.6 Mental workload

In completing the NASA RTLX after each trial, the subjects rated rate the task they had just completed in terms of mental demand, physical demand, time pressure, performance, effort and frustration level. An average score for each dimension was calculated. Compared to the control condition, subjects reported they experienced less physical demand, and that their driving performance improved when the car was fitted with a general speed limiter. However they reported that their frustration level was significantly higher in the speed limiter condition compared to the control condition.

5 Interpretation

The results in general indicate that driver behaviour does change when speed limiters are in use. In car following scenarios there appears to be a shift towards safer behaviour whereby less time was spent at short headways. This can not be attributed to a system effect, as the lead car was travelling slower than the subject's maximum speed of 30 mph. It is possible that being speed-limited discouraged subjects from attempting to overtake. Such an effect on car following, for roadside signs forbidding overtaking, was found by Summala (1980). Where subjects were not speed limited they could not overtake, due to oncoming traffic, but in the process of attempting to, adopted short headways. The results suggest that if drivers are waiting for an opportunity to overtake, accident risk increases by inducing very short following distances.

In addition, the frequency of traffic light violations decreased when drivers were speed limited. The frequency is partly attributable to a system effect, as being speed limited meant drivers were travelling slower and thus had more time to make the decision as to whether to run the red light or not. But being speed-limited, they may also have felt unable to put on extra speed in order to jump the lights.

In many respects, therefore, driver behaviour improved in scenarios where there was an opportunity for behavioural adaptation to the system, so that the speed control had a calming effect. In addition, the impossibility of exceeding the speed limit would of itself bring about substantial safety benefits. The effects of the system on younger drivers — the inability to drive fast on the approach to junctions — is particularly gratifying, as is the reduced speed variance on curves.

On the other hand, the results of the subjective mental workload measures indicate that feelings of frustration increased when drivers were speed limited. This increased frustration is possibly reflected in the riskier gap acceptance that was observed in the speed limited condition. Junctions account for 70 percent of injury accidents on urban roads (Department of Transport, 1995), and thus the introduction of a system that increases risk-taking at junctions is likely, in this respect at least, to have detrimental effects on the number of accidents.

6 Further Issues

There remain a large number of unresolved issues, before a decision is made on whether to implement speed control on a national or even a European basis. Among these are:

- Hardware design: What is the most effective and tamper-proof mechanism for limiting vehicle maximum speed? Should an element of automatic braking be incorporated, so that retardation is not too slow?
- Communications: Should the communications be beacon-based, perhaps using the Dedicated Short-Range Communications (DSRC) architecture, being adopted for other telematics systems? Or should the system be basically autonomous, relying on an on-board CD-ROM combined with a Global Positioning System?
- Fleet: Should all the motorised vehicle fleet, except perhaps for emergency vehicles, be fitted? If so, how are motorcycles to be equipped and if they are not will this result in the unfortunate effect of making motorcycles especially attractive to habitual speed violators?
- Implementation strategy: Should the initial implementation be on urban roads, where there are particularly large benefits to be secured in terms of pedestrian accidents? Or should it be on rural roads, where there are particularly large numbers of accidents involving loss of control and overtaking where excessive speed is perhaps the major factor? If an infrastructure-based system is chosen in the form of roadside beacons, should these first be installed at accident blackspots or would it be more cost-effective in the long run to equip all roads early? This question is particularly relevant for the rural non-motorway roads, where speeds are not generally higher than the speed limits, but are excessive at certain locations, particularly on substandard horizontal curves.

- Effects on safety: What are the predicted benefits in terms of accident savings from a full implementation of speed control? Estimates of the safety effect of speed control vary from a UK estimate of an 8 percent reduction in injury accidents from a system that enforced current speed limits (Perrett and Stevens, 1996) to a Swedish estimate of a reduction in injury accidents from a more sophisticated system in the range of 19–34 percent when estimating conservatively and in the range 24–42 percent when estimating optimistically (Várhelyi, 1996).
- Alternatives: How does speed control compare in cost-effectiveness with more traditional approaches to safety engineering, in particular to traffic calming?
- Side effects: Would the system have benefits or disbenefits in terms of traffic efficiency, fuel consumption and emissions?
- Attitudes: What are current public attitudes towards speed control and indeed towards some of the alternatives, such as traffic calming?

These and other questions are currently being addressed in the new project "External Vehicle Speed Control", funded by the UK Department of the Environment, Transport and the Regions, in which the University of Leeds and the Motor Industry Research Association are partners. This is a three-year project, beginning in February 1997, which includes both simulator work and on-road trials with one or more equipped vehicles. It is not currently envisaged, however, that there will be any large-scale demonstration of speed control in this project. Instead a more experimental approach is being used to address specific issues in controlled conditions. This approach would appear, therefore, to be complementary to that being adopted in other countries and in particular to the large-scale trials being planned for Sweden and the Netherlands, which should provide information on behavioural adaptation in the longer term.

7 References

Byers, J.C., Bittner, A.C. and Hill, S.G. (1989). Traditional and raw task load index (TLX) correlations: are paired comparisons necessary? In: A. Mital (ed.), Advances in Industrial Ergonomics and Safety I.

Carsten, O.M.J. and Gallimore, S. (1996). The Leeds driving simulator: a new tool for research in driver behaviour. In: A.G. Gale (ed.) Vision in Vehicles – V. Amsterdam: Elsevier.

Perrett, K.E. and Stevens, A. (1996). Review of the potential benefits of road transport telematics. TRL Report 220. Transport Research Laboratory, Crowthorne.

Plowden, S. and Hillman, M. (1996). Speed Control and Transport Policy. Policy Studies Institute, London.

Summala, H. (1980). How does it change safety margins if overtaking is prohibited: a pilot study. Accident Analysis and Prevention, 12 (1): 95–103.

Várhelyi, A. (1996). Dynamic speed adaptation based on information technology: a theoretical background. Bulletin 142. Department of Traffic Planning and Engineering, University of Lund.

The effects of speed limiter in cars.

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1. Introduction

The significance of speeds in determining the safety level in road transport is well appreciated by most researchers in the area. One very important finding is that even small reductions of average speeds may result in significant reductions of fatality risk or risk of severe injuries. (Elvik et al 1995). For instance a 10 km/h reduction of average speed on a rural road on average results in a 35% reduction of fatalities and a 27% reduction of injuries (Carlsson 1980).

Due to the very significant effects of speed reductions it has been a major task both among researchers and practitioners to find strategies that have an influence on the speed choice of motor vehicle drivers. The conclusion of efforts made so far is, however, that the influence on mean speeds on Swedish roads are difficult to identify. Regular speed measurements in Sweden show for instance that median speeds on rural roads with a speed limit of 90 km/h is 93 km/h, and on roads with a speed limit of 70 km/h 81 km/h. (Andersson & Nilsson 1997). Besides speeds are increasing slowly over time, not decreasing.

Even though our understanding of reasons behind excessive speeds and poor speed adaptation is high, the strategies to change this have been unsuccessful. Campaigns have in most cases proven to produce only short term changes. The same is valid for speed enforcement efforts which also have an effect only in a limited area adjacent to the enforced location(s) (Várhelyi 1996). Automatic speed control with movable cameras have in some countries shown promising effects, even though they still not produce any major change of behaviour (Pasanen 1996).

The most efficient measures so far are linked to the physical environment. Ordinary speed humps to control speeds in residential areas are very efficient. They reduce average speeds to somewhere between 20 and 25 km/h with a quite small speed variance. The problem, however, is again that the effects are local and that the cost of large scale implementation is quite high. Besides there are still no really efficient measures of the same kind that can be used on arterial roads where the safety problem is at its peak. This is primarily due to the fact that arterials carry heavy traffic - especially buses - that are facing big problems to cope with humps. Research is going on in many countries but any final solutions can not be foreseen yet (Towliat 1997).

Researchers have for a long time insisted on the importance of applying a systems approach to safety problems. In the case of speeds, however, the systems approach has up till recently not included the importance of the vehicle. This is surprising in view of the fact that private cars to day have a speed performance capability which by far exceeds what is the highest speed limit in almost all countries.

Our research has focused on this paradox, and we have asked ourselves if it would be possible in one or the other way to harmonise the warrants produced by the society expressed in speed limits and general rules about speed adaptation with the speed performance capability of cars. This led

us to the concept of Speed Limiter (SL). The basic idea is to install a device in the car that limits its maximum speed to the prevailing speed limit. Except for this limitation the car works as any car.

We have carried out research on the SL-concept for more than ten years. It has all the time been based on the precondition that the SL is automatic and obligatory, i.e. it sets the maximum speed to the prevailing speed limit automatically and the driver can not change the maximum speed himself.

This is a different approach compared with traditional research in this area where the focus is on trying to influence speed behaviour via a change of attitudes or norms (see e.g. the Theory of Planned behaviour (Ajzen & Fishbein 1980)). We do it the opposite way; we start by forcing a change of behaviour, and presuppose that drivers will accept the new behaviour. The basic hypothesis is that the change imposed by the speed limiter is not very dramatic - and as the drivers can not do anything to override the system - they will adapt to the new situation and gradually accept it. Our initial tests in the city of Lund make us believe that this will be true for the vast majority of drivers. There will be a reduction of speeds - and if drivers accept the concept as assumed - the reduction of speeds will lead to a reduction of injury risk which is as big as the one achieved at other changes of speeds, e.g. when the speed limit is reduced.

2. Field tests - history

The first trial with a speed limiter in passenger cars was carried out in France (Saad and Malaterre, 1982), where the equipment was evaluated in real driving situations by voluntary test drivers. The drivers could set the speed limit, which could not be exceeded if the drivers did not release the equipment by a separate manoeuvre. The actual use of the limiter depended on the traffic volume and the actual speed limit on the road. The test drivers gave priority to adapting their speed to the traffic situation and such adaptation meant small changes in speed around the speed limit. To "float with" the other cars, the test driver had to set free the speed-limiter quite frequently, which was tiring and painful. Most drivers set the top speed on the limiter significantly above the speed limit. The lower the speed limit on a road, the bigger the difference between the set top speed on the limiter and the speed limit on the road. The knowledge of the lack of acceleration resources meant that in presumptive overtaking situations a large number of drivers renounced the overtaking manoeuvre. The test drivers thought that the speed control was too effective, they experienced that their freedom of action was too limited. These speed-limiters were primitive and uncomfortable in comparison to today's technology and they caused irritation among the test drivers.

A similar device is the active gas pedal, which provide a gas pedal counter-force whenever the driver tries to depress the pedal beyond a pre-set speed limit. The system is not really a collision avoidance system, since in emergency situations drivers have to rely solely on themselves and intervene. The system was successfully field-tested in a fleet of university-owned vehicles driven by employees. Apparently, the pedal resistance is sufficient to remind drivers of the speed limit, and the extra effort required to go faster is sufficient to deter them from speeding (Schulman, 1985).

However, in case of emergency, the driver can overcome the pedal resistance by pressing with great force, and thus speed up.

A field study with a speed limiter in built-up areas in Lund, Sweden (Persson, et al., 1993), showed that the test drivers drove at lower speeds, with the speed limiter, on links between intersections, and slightly higher speeds at intersections when turning. The mean speed decreased on links by between 2 and 8% with the speed limiter. There was a slight tendency to compensate for the low speeds on stretches by driving faster (by 2-3 km/h) through the intersections. It might be an unconscious compensating behaviour. Data from behaviour observations showed a clear increase in the proportion of correctly kept distances to the car ahead (even on sites with speeds lower than the actual speed limit). On the other hand, there was a slight increase of incorrect behaviour towards other road-users at intersections. When driving with the speed limiter, drivers were more often passed by other cars on 4-lane roads. Most of the drivers were positive to the speed limiter with regard to general impression, feeling of hindrance and stress but negative about whether the speed limiters try the patience of the drivers or not. Eighty-five percent of all the drivers were positive to the experienced feelings of safety. Two thirds of the answers, after driving with the speed limiter, were positive concerning the effects of the speed limiter with regard both to car drivers and to unprotected road-users. The most often mentioned advantage for drivers was smoother rhythm in traffic and better preparedness for unprotected road-users. The most commonly meant disadvantages for drivers were that it would be impossible to accelerate and sometimes exceed speed limits.

3. Theoretical approaches

Speed limiters on rural roads

Gynnerstedt et al (1996) studied the effects of speed limiter in cars with a simulation model on two-lane rural roads at different traffic volumes in Sweden. All vehicles were assumed to be equipped with speed limiters set on the current speed limit. The results showed that:

- The average speeds were lower in the speed limiter scenario, although the difference seemed to diminish the denser the traffic was.
- The standard deviation decreased in the speed limiter scenario, i.e. the speed distribution became more homogenous.
- The number of overtakings decreased, which could increase the percentage of cars driving in platoons.
- The number of critical overtakings increased, in high traffic volumes (1500-2000 vehicles/hour) the increase was heavy.
- Fuel consumption was reduced in the speed limiter scenario in traffic densities below medium (1500 vehicles/hour).

The safety effects of a dynamic speed limiting system

In a theoretical study the possible safety effects have been estimated of a dynamic speed limiter, controlling the maximum speed at adverse weather conditions and at interactions between motor vehicles and unprotected road users.

Accident risk at adverse conditions (darkness, reduced friction and visibility) increases dramatically. It is obvious that speed adaptation in critical conditions is unsatisfactory (see table 1).

Table 1 *Changes in speeds and risk levels (accidents/vehicle km) in different critical road and light conditions compared to normal conditions.*

Condition	Change in speed	Change in accident risk
wet road	0 to -6%	+10 to +50%
slippery road	-7 to -11%	+400 to +800%
darkness	+9 to -7%	+30 to +100%

On roads in Sweden with a 70 km/h speed limit, the average speeds do not go below the speed limit in any of the critical conditions. In darkness the average speeds are above the speed limit on almost all types of roads. With regard to safety, it seems much more difficult to adapt speed to actual circumstances, than to adapt speed to the speed limit.

In encounters with other road-users, drivers do not lower their speeds sufficiently to maintain a readiness to be able to handle a possible unexpected dangerous situation. In Sweden pedestrian presence at a zebra crossing has little or no speed-reducing influence on approaching vehicles (Várhelyi 1996a). In encounters with pedestrians, it is not uncommon that car drivers use high speed as an expression of strength or demand for priority. When the approaching car and the pedestrian are on a collision course, 3 out of 4 drivers maintain the same speed or accelerate and only 1 out of 4 slows down or brakes. It is reasonable to assume that maintained high speed (even exceeding the speed limit of 50 km/h) or accelerating can be interpreted as a signal from a driver that he or she do not intend to give way to the pedestrian at the zebra crossing.

A reasonable criterion for the appropriate highest speed values in critical conditions is that the driver must be able to stop the vehicle within the same distance whether on wet and slippery roads or on dry roads, within the visibility distance, as well as keep the car on the road at sharp bends. The speed level which gives the same stopping distance on wet roads as on dry roads is between 82 and 92% (depending on the friction value) of the speed on dry roads. On slippery roads the level is between 50 and 74% of the speed on dry roads. In darkness the stopping distance must be shorter than the lit-up visibility distance for the vehicle to stop in case of an unexpected stationary object ahead. The speed in darkness and with low beam headlights should not exceed 60 km/h on dry roads, 50 km/h on wet roads and 40 km/h on slippery roads (on non-hilly roads). With high beam headlights these values are 107-127 km/h on dry roads, 98 km/h on wet roads and 74 km/h on slippery roads. In conditions of haze, fog, rain or snowfall, according to the most stringent criterion, the stopping distance should be a maximum of half the visibility distance in order that an oncoming vehicle, emerging unexpectedly on the wrong side of the road, can also stop in time if the risk of a collision arises.

In built-up areas where motor vehicles and unprotected road-users share the same space, the general principle for speed adaptation should be that the vehicle speeds should not exceed 30 km/h at interactions with unprotected road-users. This would result in a generally smoother interaction between vehicles and pedestrians/cyclists, and a dramatically reduced risk of injuries compared

with to-day (Hydén, Odelid, Várhelyi 1995). The dynamic speed limiter would in these cases work as an "electronic hump", which means that the vehicles would always be slowed down at these locations irrespective of pedestrian presence. In a more sophisticated scenario, the presence of other road-users is detected either by road-side equipment or in-vehicle equipment and the vehicles' maximum speed is lowered only in case of the presence of unprotected road-users. Such a system could be implemented in places and at times with few unprotected road users (outer town areas, low traffic times, e.g. night-time) where it is not desirable to lower the speed generally and where it is easier to detect unprotected road-users on collision course with vehicles.

The dynamic speed limiter would set the maximum speed in critical conditions and situations to a pre-determined appropriate level. The road friction, visibility and light conditions are constantly monitored. This on-line information, together with other relevant data (such as speed limit, gradient, curve radius, superelevation), constitutes the base for the calculation of the current appropriate highest speed.

The information system should have the following functions:

- Constant monitoring of characteristics of different locations and various critical situations according to pre-determined criteria.
- Calculation of the current maximal allowed speed.
- Transmission of information to the vehicle.
- Informing the driver of the prevailing conditions and the current maximal allowed speed via a display.
- Setting the speed limiter constantly on the current maximal allowed speed.
- Informing the driver visually and/or audibly and by a gradually increasing counter-force of the gas pedal when the increasing speed of the vehicle comes close to the actual limit.
- Informing the driver visually and/or audibly and by counter-force of the gas pedal when the current maximal allowed speed changes to a lower level.

In a scenario where all vehicles are equipped with speed limiters and therefore do not exceed the prevailing speed limit, with the assumption that vehicle mileage remains unchanged, the proposed speed adaptation system would lower the number of police-reported injury-accidents by between 20% and 40% in Sweden.

4. A field trial of automatically initiated speed limiter

Twenty-five vehicles - private cars used in real traffic - were equipped with a Speed Limiter (SL). The aim of the project was to investigate drivers' attitudes and behaviour when using the SL-function in their daily life for a longer period of time.

The whole urban road-network of the city of Eslöv in south Sweden, with 30.000 inhabitants, was included in the field test. At every entrance/exit to the city where the speed limit changed transponders were installed. Eight major streets and six minor streets completed the installation of the transponders.

When an SL-equipped vehicle on its way towards the city passes a transponder the speed limiter is automatically activated to 50 km/h. In the other direction the speed limiter is changed to 90 km/h.

The SL-function is automatically activated to the speed limit 50 km/h when starting the vehicle. (It is presumed that the majority of starts are done in urban areas). The prevailing maximum speed (i.e. the speed that the SL is set on) is indicated on a display on the dashboard.

Test drivers were selected at the two major employers in the city of Eslöv : the Municipality of Eslöv and Procordia Food AB. The two organisations were asked to put up a list of persons who used a car daily in Eslöv, either in their work or as a commuter between the home and the work. A mix of different ages and sexes was asked for. From these lists the test-persons were selected and asked if they were interested to be engaged as test-drivers of the SL-function. 10 female and 16 male test drivers were engaged for a period of 6 - 8 weeks. The 25 vehicles were a mix of private and company cars of different age and model.

The evaluation methods used in the project focused on drivers' attitudes to the SL-function and how the SL-function influenced their driving.

Initially a reference ride (16 km, without SL) was conducted to establish the drivers "normal behaviour". The route included different traffic conditions typical for the city of Eslöv.
An interview was conducted before the drivers started using the SL-function.

The procedure was repeated after two months use of the speed limiter.

Evaluation methods used

Interviews
The questionnaire was composed to cover the following subjects:

*Traffic safety and risk awareness,
*Speed and distances,
*Comfort and willingness to pay for an SL
*Pros and cons
*Measures and regulations,
*Interplay with other road users,
*What would happen if all cars were equipped with Speed Limiters

Observation of driver behaviour
One observer accompanied the driver each time around the test trip. The observer who sat in the front next to the driver had the task of identifying various types of behaviour on the driver displayed. The observer was trained to observe and note the occurrence of a variety of inappropriate behaviours as well as any traffic conflicts occurring.

Speed logging - Speed-profiles
The installed speed limiter was connected to a computer in order to collect speed data during driving with the vehicle. Collected data was used to calculate speed distributions and time consumption.

Interview results, examples

Question: How often do you feel the SL-function when using your car?

Every time	almost every time	often	seldom	never
62%	26%	4%	8%	0%

Question: How were your feelings regarding the feed back from the accelerator?

Excellent	good	all right	poor	disgusting
8%	58%	26%	8%	0%

Question: What did you like the SL-function you have been used compared to your expectations?

more positive	as expected	more negative
73%	15%	12%

Question: What is your attitude to include the SL-function for all different speed limits in urban areas?

very positive	++	+	0	-	--	very negative
39%	22%	23%	8%	8%	0%	0%

Question: What is your experience of the SL-function as...

	agree	+	0	-	disagree
..a security?	12%	38%	38%	8%	4%
..a support?	30%	54%	8%	8%	0%
..an unpleasant control?	0%	0%	12%	38%	50%
..a source of irritation?	4%	4%	12%	30%	50%

Question: Do you think that beeping signals and/or flashing lamps inside the vehicle would have the same effectiveness as the SL-function to keep the speed limits?

No	?	Yes
66%	23%	11%

Question: Would you be willing to pay 900 SEK for the installation of an SL in your own car

Yes	Yes, "if it is included"	No
58%	12%	30%

Results - driving behaviour, examples (the most frequently observed behaviours)

Driving speed in relation to the legal speed limits (average number of errors per driver)

Before (without SL)	After (with SL)	Difference
5,8	0,3	-5,5

Driving speed in relation to the situation at hand (average number of errors per driver)

Before (without SL)	After (with SL)	Difference
2,1	0,1	-2,0

Inappropriate interaction with vulnerable road users (average number of errors per driver)

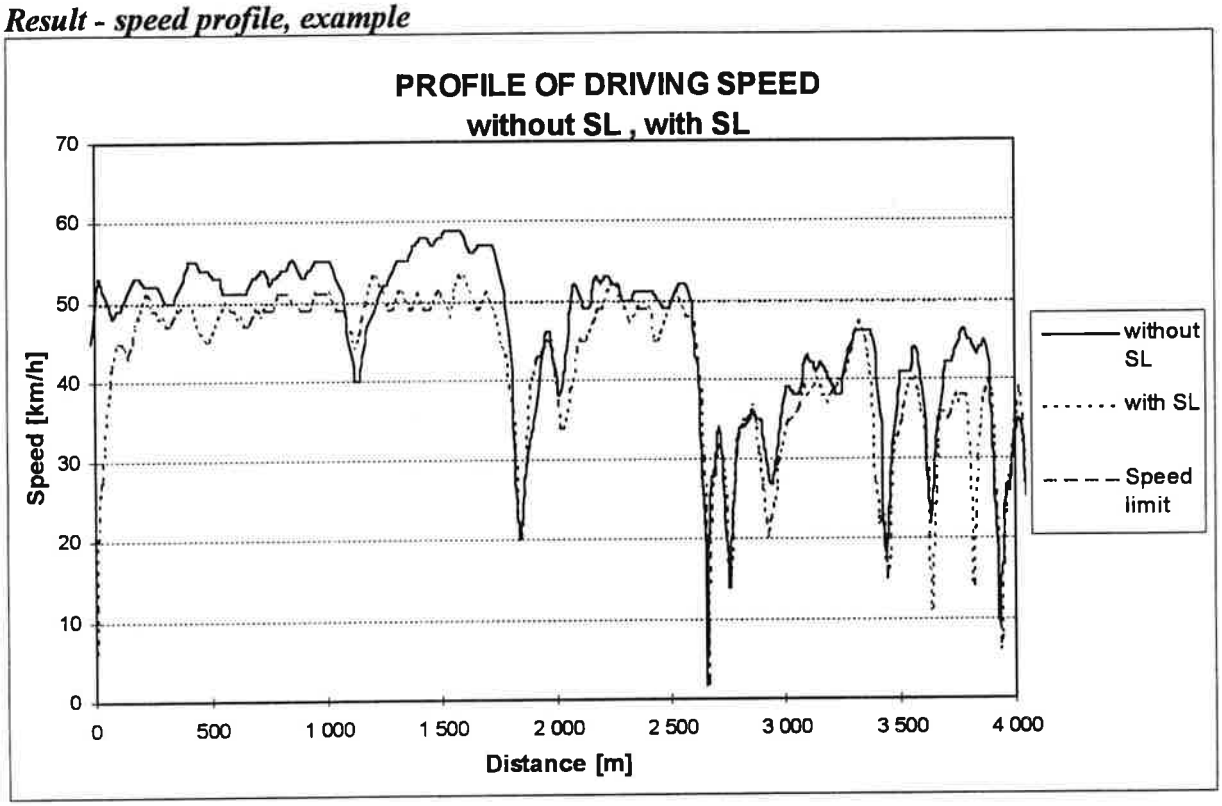
Before (without SL)	After (with SL)	Difference
2,4	0,1	-2,3

Result - Time consumption

Total time consumption recorded for the test route.

Before (without SL)	After (with SL)	Difference
1 426 sec.	1 497 sec.	+71 sec (4,9%)

Result - speed profile, example



5. Synthesis and conclusions

Earlier studies - primarily the French one - and self testing at the Department, made it obvious that the testing of an SL should be limited to urban areas in the first run. Conditions are less complex in relation to a limiting of the speed. Primarily because overtakings do not exist in the same extent as on rural roads.

The field test in Eslöv produced new insight into the effects of a static speed limiter, i.e. a limiter only linked to the speed limits existing to-day. Even though the sample of drivers was small the

results indicated very significant safety improvements; (top) speeds went down, and inappropriate speed adaptation and interaction with vulnerable road users were very significantly improved. There is the same tendency in the city of Eslöv as in the former test in the city of Lund that drivers drove a little bit faster at low speed situations, primarily in turning movements at intersections. As speeds in these cases almost always are below 30 km/h the negative consequences are quite small, at least with regard to consequences of a possible collision, i.e. severe injuries.

The interviews indicated a very clear support for the SL. The drivers appreciated it as a supporting function almost without any disadvantages. It must be clearly said, however, that some biases of the results must be expected due to psychological effects. We are addressing a small group of testers of a new system which is raising a lot of interest from the media. It is therefore likely that the testers are more in favour of the system than what can be expected later on. Still the tendencies are very strong, and as the testing also includes more operational aspects on the concept it is likely that two months of using the speed limiter would have resulted in clearly stated operational negative views, if there had been any.

Even though the sample in Eslöv was small, and the directly safety related results were lacking, the study is still very important in providing further knowledge on how drivers accept and are influenced by an automatic and compulsory speed limiter.

Our conclusion when it comes to the use of a static speed limiter in built-up areas is that our basic hypotheses regarding "smooth adaptation" and acceptance of the speed limiter were strongly supported. The synthesised results show clearly that drivers adapted quite easily to the new situation, and that they even assessed the new situation as being preferable in many ways. The behavioural observations also showed very significant reductions of unsafety related behaviours, and the reduction of speed seems to have been followed by no major disbenefits in terms of undesired new types of behaviour. Rather the contrary, the rather small overall reductions of speeds were accompanied by very significant reductions of undesired behaviours. It therefore seems very reasonable to believe that the speed reductions would be followed by injury reductions of the same magnitude as if speeds had been reduced via a reduction of the speed limit.

The results from Eslöv also supported the basic precondition that the speed limiter should be automatic and obligatory. A comparison with the French experiment, where the drivers used the limiter on a voluntarily basis, showed a much more positive attitude to the automatic and obligatory mode. Of course there may be a general difference in attitudes to speed limiters between the drivers in France and Sweden, but again the difference is so big that it seems reasonable to believe that parts of the more positive attitude to the automatic and obligatory mode was due to the concept itself. An on-going EU-project, MASTER, will give some more background as limiter tests are carried out both in Sweden, the Netherlands and in Spain.

Even though the results so far are very promising there are a number of aspects that makes it important to appreciate the fact that there is still a long way to go before any firm conclusions can be made with regard to a large (full) scale implementation of a speed limiting system. One question is e.g. to what extent the results from Eslöv are general. Are they e.g. valid if the speed reduction is bigger, which for instance would have been the case if the test had been performed in a

bigger city. And, would it work with drivers in bigger cities in general where the tempo and density of traffic is quite different?

An other important question regarding the full scale and long term implementation is whether the very small tendencies of negative side effects remain small and of less importance. In case of Eslöv it was primarily the somewhat higher speeds at turning movements at intersections that might cause problems. Will that kind of problem be amplified in the long run? Will there be any other types of compensatory behaviour that we were not able to detect in Eslöv - or that were not valid in Eslöv but might be so under other conditions?

The question about small scale versus large scale has of course not been tackled in the Eslöv tests. Our hypothesis is that there is primarily a "hidden safety potential" as a large scale implementation probably would lead to smoother flows with less speed variation and less variation in drivers' expectations. Only large scale experiments can help us in this case.

There is one very "sophisticated" hypothesis that the present testing has not been able to cover very clearly. That has to do with delegation of responsibility ("the system takes care of everything"). This phenomenon might lead to a reduced vigilance which can result in negative consequences for safety. It is our understanding that this kind of effects are quite valid for new systems in general, but extremely difficult to detect because new systems are always introduced gradually and over quite a long time period. We believe, however, that as we are focusing on the problem already now, we might be able to design studies later on specifically focusing on this potential problem.

The hypothesis above was "sophisticated" because the effects were very difficult to detect. There are more examples of the same kind. We will only give three more examples here:

1. "Frustration might arise, as a result of having no chance of making up time during the journey". Will this kind of frustration arise and in that case how will drivers cope with it?
2. "The system would make it difficult to predict journey time, especially under winter conditions". The same questions as above are valid again.
3. "The driver does not have to read the speedometer all the time as he confidently knows that he is not exceeding the speed limit". Is this true and how will the driver adapt to the new situation? How will the driver use the attention he formerly used on reading the speedometer?

Further research is clearly needed. The former tests in real traffic conditions, e.g. in Lund and in Eslöv, has shown that it is quite possible to carry out tests in real traffic even when the system is used in a very small scale. The problems of studying all the hypotheses in the small scale tests will gradually disappear when the scale of the tests is increasing.

All the comments made so far have only dealt with the static speed limiter. Obviously there is a great safety potential in managing speeds also in dynamic situations as defined in chapter 2. This demands, however, new types of tests. How will for instance drivers cope with "new types" of changes of the speed limits, and how will drivers adapt their behaviour. What changes will work - e.g. what speed limits would be imposed in snow, rain, darkness, etc. - and how should these dy-

namic changes of the speed limit be introduced in order to produce the optimal adaptation of behaviour from a safety point of view. These important questions produce a great and new challenge for researchers, hopefully not only for researchers in Sweden! It is really time for a much more widespread approach all over the globe.

References

Ajzen I.; Fisbein M. Understanding attitudes and predicting social behaviour. New Jersey: Prentice Hall. 1980

Andersson G.; Nilsson G. Speed management in Sweden. Swedish National Road and Transport Research Institute, Linköping, Sweden; 1997.
Carlsson, G. Beräkning av förväntad olycksreduktion vid förbättrad efterlevnad av gällande hastighetsgränser. VTI Meddelande 222, Linköping; 1980.

Elvik, R et al. Utkast til reviderte tiltakskapitler i Trafikksikkerhetshåndboka: Trafikkregulering. Transportøkonomisk Institutt, arbeidsdokument, TST/0687/95. Oslo; 1995.

Gynnerstedt G.; Risser R.; Gutowski A., 1996.: Traffic flow behaviour and a speed limiting function - A simulation study. Arbetspapper KTH, Stockholm.

Hydén C.; Odelid K.; Várhelyi A. Effekten av generell hastighetsdämpning i tätort - Resultat av ett storskaligt försök i Växjö. Institutionen för Trafikteknik, LTH. Bulletin 131, Lund; 1995.

Persson H.; Towliat M.; Almqvist S.; Risser R.; Magdeburg M., 1993.: Hastighetsbegränsare i bil. Fältstudie av hastigheter, beteenden, konflikter och förarkommentarer vid körning i tätort. LTH, Lund.

Saad F.; Malaterre G. La regulation de la vitesse: Analyse des aides au controle de la vitesse. ONSER. 1982

Schulman R., 1985.: The deaccelerator project: Research report. The Deacceleration Corporation. Kalamazoo, MI., 1985. In: Bower, G.H., 1990.: Incentive programs for promoting safer driving. Enforcement and Rewarding Strategies and Effects. Proceedings of the Symposium in Copenhagen, Denmark.

Towliat M. Trafiksäkerhetsproblem och åtgärder för gång- och cykeltrafikanter i mötespunkter med bilister. Rapport 7151. Institutionen för Trafikteknik, LTH, Lund; 1997.

Várhelyi A. Dynamic speed adaptation based on information technology - a theoretical background. Lund University, Sweden, 1996.

Várhelyi A. Drivers' speed behaviour at a zebra crossing. KFB-meddelande 1996-16, Stockholm, Sweden.

Initial experience with Traffic Conflict Techniques in Brazil

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1 - Introduction

This work is intended to give a brief overview of road accidents and describe the first two trials using traffic conflict techniques in Brazil. The first of these took place in August 1991, in São Paulo, and the second in February 1995, in Rio de Janeiro.

The two trials showed that *traffic conflict techniques* (TCT) can contribute significantly to a better analysis and understanding of the problems, leading to a better application of available resources. On top of this, they can help shorten the time needed to put into practice possible countermeasures.

It is estimated that 500,000 fatalities per year result from road accidents through the world, and almost 50,000 of these in Brazil alone (Volvo, 1993). Consequently, the subject has received special and growing attention from governments and agencies and many steps have been taken to reduce the number and/or gravity of occurrences. However in Brazil as in other developing countries, this process has not yet developed, while the accident statistics are dramatic. Table 1 gives a general overview of the situation in the last two years.

Table 1- Accident statistics in Brazil

	1995	1996
Population	153 725 000	156 859 885
Vehicle fleet	26 609 232	27 519 278
Fatalities	25 513	26 903
Inhabitants / vehicle	5.85	5.70
Fatalities / 10,000 vehicles	9.59	9.78
Fatalities / 100,000 inhabitants	16.6	17.15

Source: DENATRAN (National Highway Department), 1997

It should be pointed out that these are the official statistics, but it is estimated that these are

underestimated by 100%, due to failures in collecting and recording data. It is also worth noting that 44% of the victims in 1995 were pedestrians. It should be noted that in developed countries, the number of fatalities per 100,000 inhabitants is between 10 and 15, while fatalities per 10,000 vehicles is between 1.5 and 3.5 (Ogden, 1996).

It is calculated that the cost generated amounts to U$ 4 billion annually (almost 1% of GDP), as well as at least 350,000 injured, who occupy 63% of the emergency beds in public hospitals (Volvo, 1993).

The solution will require large investments, which will depend on a good understanding of the causes of accidents. This knowledge has been traditionally acquired through the compilation and analysis of accidents reports.

In developed countries this is a systematic procedure which has been going on for a long time. Each accident is registered and all the relevant information is sent to the agency responsible for its analysis. According to the U.K. Transport Research Laboratory (TRL, 1991), all the developed countries consider good quality data to be of crucial importance, in order to correctly define the problem and the measures to be taken. This data should be complete, all encompassing and reliable, providing the greatest amount of information possible. Clearly, in practice, this is very hard to achieve and even the most developed countries have their difficulties:

- there is a considerable degree of under-registering of accidents;
- the information registered is not always sufficient for a Traffic Engineering analysis.

As well as the failure to register accidents in Brazil, there is the problem of the quality of the data. There is no single, standardized form for registering data, at a national or municipal level (Braga et al., 1996), causing doubt as to the reliability of the data obtained. This gives rise to another problem; the evaluation and monitoring of measures taken to improve safety.

As an accident is a relatively uncommon event, it takes quite a long time to accumulate conclusive information on a given location. Meirelles (1990) observes that the U.S. Federal Highway Administration (FHWA, 1989) recommends a period of study of 3 years before and 3 years after an improvement for its adequate evaluation.

Given these difficulties, a need arises for alternative sources of data for the evaluation of a site or area, such as behavioural studies, the relation between traffic volume and accidents, traffic conflict studies, signal obedience studies, etc.

One of the best of these alternatives is *traffic conflict studies*, in view of the close correlation with accidents (Institute for Road Safety Research, 1984). This procedure originated in the USA in the 1960's and was quickly transformed into an excellent technical support tool for the area and adopted in various countries.

2 - Traffic Conflict Techniques

The study of traffic conflicts arose out of the need for better and quicker information than that furnished by accident data. The first study to produce an indicator for predicting road accidents, which could be used to better visualize the factors which cause accidents, was

developed by Perkin and Harris in 1967.

From that point on, several countries set about perfecting traffic conflict techniques and a consensus was reached as to a definition of conflict:

> "A situation of interaction between two road users (or between one user and the environment) which will necessarily lead to a collision if one of the protagonists does not take evasive action" (Muhlrad, 1988).

Similar general definitions of traffic conflict appear in other works which are today classics in the field (Hydén, 1987; FHWA, 1989). However, operational definitions vary significantly with respect to the range of incidents, from normal conflicts to near accidents, as well as how to classify and analyse them.

Various countries began to test and utilize these studies, obtaining positive results in the evaluation of road safety. This methodology permits a rapid monitoring and analysis of the safety of a site even without the accident records. Oppe (1985) observes that the analysis of the road safety should be the critical event, and not the accident. Thus, improving road safety implies understanding how the accident happened. TCT, through direct observation, yields more information, in this respect, than accidents records.

One major difference between the analysis of road safety through accident records and through conflict data is in scope. While accidents records cover the whole highway network, with all its problems, conflict data cover only selected locations.

It is clear that on a general basis, accident records continue to be indispensable. However, in a precise analysis, conflict data yield more and better information, in a shorter period of time. Ideally, these techniques would be used as a complement to an analysis based on accident records.

In addition, there evidently exist numerous sites with no record of accidents. In these cases, TCT become an invaluable tool for the technicians, being the only source of adequate information.

Their applications are varied:

- "before and after" studies for evaluation of the implementation of corrective and/or preventive measures;
- the study of factors involved in accidents (in order to visualise the conditions which provoke them);
- to supplement accident record data;
- to substitute accident records (without eliminating them altogether) in the evaluation of critical points;
- to evaluate driver performance (Risser, 1985).

All the techniques in use share points in common: they are based on the evasive manoeuvre of a road user who had been put at risk by another, or by the environment; the observation of conflicts was performed directly, in the field, by trained observers; and a scale is adopted, based on the severity of the conflict (normally varying from minor to major).

Normal local speeds are not taken into account when classifying a conflict because, as well as being difficult for the observers to evaluate, it does not serve to define a conflict, but merely increases the potential gravity of an accident.

Muhlrad (1986) defines thus the concept of a TCT:

> *"it is the set of definitions and procedures which permits the gattering of conflict data and its utilization as an indicator of risk".*

3 - Initial experience in Brazil

The first trial of conflict techniques in Brazil took place in August 1991, in São Paulo (Pietrantonio, 1991). This experiment utilized the American technique, analysing only vehicle conflicts, at a nonsignalized X intersection. This intersection had 16 accidents in 1990, all involving lateral collisions. Of this total, only 8 have clear information regarding the accident.

The second Brazilian experiment took place in February 1995, in Rio de Janeiro (Guedes, 1995). The French technique was utilized at a T intersection where 7 accidents occurred during the period 1/12/94 to 19/3/95.

3.1 The São Paulo experience, 1991

3.1.1 Main characteristics of the American technique

The chief characteristics of the American traffic conflict analysis technique (FHWA, 1989) are as follows:

- traffic conflicts are not classified on the basis of their severity;
- classification is essentially based on the type of manoeuvre involved;
- analysis of the data is based on a comparison between observed conflict levels and 'normal' conflict levels.

Data analysis may also estimate expected accident frequencies, based on the rate of accidents per million conflicts.

3.1.2 Site Characteristics

The site chosen for the field survey was an urban X intersection. Both roads were one-way, one being a main road - A, connecting main arterial roads, the other a secondary road - C (Figure 1). As well as STOP signs, there was also a luminous sign, with a flashing yellow light, and signs warning of a dangerous junction.

Traffic flows during the 11 hour period (7 am to 6 pm) were 3,834 vehicles on road A (with a significant proportion formed into platoons by the traffic light at a nearby junction) and 2,255 vehicles on road C. In other words, an average weekday volume of less than 10,000 vehicles. The movement of pedestrians was significant, without being elevated or intense.

The road surface was in good condition and road A presented average to high speeds, depending on traffic flow (50 k.p.h at the morning peak to over 70 k.p.h at the afternoon peak). The area has intense and varied commercial activity, which includes buildings in the immediate vicinity of the junction (these is a drugstore on each of the roads). The intersection also marks the point of a change in regulations governing parking, which is

prohibited in the subsequent stretch (transforming it from 2 lanes into 3).

The site was chosen due to its accident record and was considered especially suitable, in view of the low movement (and types of conflict), for a first contact by researchers with the technique.

3.1.3 Training the observers

Six observers from the regular team of the São Paulo municipal Traffic Engineering Company (CET/SP) were used. Training consisted of an afternoon of lectures on theory and an afternoon of field practice followed by an afternoon for discussion of the field practice and instructions for the research itself, which was performed in a single day (during a standard period, between 7 a.m. and 6 p.m.).

The observers were divided into two groups (corresponding to two research shifts), responsible for the collection of data on conflicts (6 types, one of which related to pedestrians), traffic volume on both roads and speeds on the main road.

3.1.4 Data collection

During the trial, one researcher observed the conflicts while the other two measured volume and speed. Following the normal procedure for applying the technique, only the main road had a conflict observer, as braking on the secondary road is fundamentally a consequence of the right of preference. In situations where the conflict was not on the main road, it was necessary to note the characteristics of the event and, if necessary, define the special type of conflict.

The number of conflicts observed per sub-period (between 5 and 20 minutes) did not present problems for registration and special events did not command attention. The demands of observation were tolerable, due mainly to the periodic intervals between sub-periods.

The short period of observation required is one of the advantages of the American technique, as the less strict concept of conflict allows the collection of a greater amount of statistically significant data in a shorter period of observation. However, for such a period, only the intersection's conflict data totals are significant. To obtain statistically significant data per type of conflict, the period of observation would have to be extended to between 2 and 5 days, depending on the type of conflict considered critical at the site.

3.1.5 Results

The results, extrapolated for each time period, are summarised in Table 2. Same direction conflicts were frequent, mainly due to normal manoeuvres such as lane changing for overtaking, speed adjustments within the traffic and those due to the change from 2 lanes to 3 (explained previously). Hazard provoking manoeuvres, such as stopping, parking, loading and unloading of cargo, were other contributing factors in same direction conflicts.

Table 2 - Conflict counts

Time Period	Same Direction	Junction	Pedestrians	Total
7:00-8:00	14,5	8,4	0,0	**23,0**
8:00-9:00	21,8	11,5	1,2	**34,5**
9:00-10:00	16,6	8,7	4,4	**29,7**
10:00-11:00	27,8	24,4	1,3	**53,6**
11:00-12:00	15,5	13,9	2,3	**31,7**
12:00-13:00	23,3	10,3	1,4	**35,0**
13:00-14:00	27,3	10,8	4,5	**42,6**
14:00-15:00	30,1	15,8	3,3	**49,3**
15:00-16:00	26,0	10,3	0,3	**36,5**
16:00-17:00	17,2	11,9	0,0	**29,1**
17:00-18:00	18,8	7,7	0,0	**26,4**
TOTAL	**239,0**	**133,5**	**18,8**	**391,3**

Conflicts at the junction involving vehicles coming from the secondary road were less frequent, but the incidents provoked were clearly of a more serious nature. This observation was corroborated by the accident reports (in 1990, the 16 accidents which occurred all involved lateral collisions). Field observation showed that despite there being sufficient opportunity to make the crossing, vehicles from the secondary road frequently violate the preference.

For same direction conflicts, the normal count would be 410 (with 90% reliability) or 490 (with 95% reliability). The total observed suggests that there is no safety problem concerning this type of conflict (a conclusion born out by the accident records).

For conflicts at the junction, the normal count would be 24 (90% reliability) or 29 (95% reliability). The total observed leads to the conclusion that there are safety problems related to this type of conflict (with reliability in excess of 95%).

Through analysis of the site, various factors were identified which could explain the gravity of conflicts at the junctions: the lack of conspicuousness of the junctions (due to the continual parking of vehicles on the secondary road, before and after the intersection), the lack of conspicuousness of the STOP signs (for the same reason), problems of visibility of the main traffic flow (as parking is permitted, and fully utilised, on the approach side) and excessive speeds on the main road (in excess of 70 k.p.h., and even 80 k.p.h.).

Using the American parameters, the accident forecast for the site would suggest an absence of rear-end collisions (typical of same direction conflicts) and approximately 13.6 lateral collisions (typical of junction conflicts). This forecast is close to the figures observed (a total of 16 recorded accidents, all lateral collisions).

3.2 The Rio de Janeiro experience, 1995

3.2.1 Main characteristics of the French technique

The principal characteristics of the French technique are:

- traffic conflicts are classified according to their severity into light, medium or serious conflicts;
- this classification is done for each conflict;

- analysis of the road safety at the site comes from individual analysis of each conflict, in the same way as an analysis based on accident reports.

3.2.2 Choice of location characteristics

The site chosen was an urban T intersection. Both roads were two lane and one had a median (Figure 2). There was also a minor road (Rua Babaçu) just before the intersection. Traffic volume is around 2,500 vehicles/hour on a weekday afternoon. The movement of pedestrians crossing the intersection is limited, but risky.

The turn to the left, onto the Estrada do Cacuia, is controlled by a traffic light. The only other road signs are two direction signs. The width of each lane is approximately 8.5 metres.

The only controlled crossing for pedestrians is one lane of the Estrada do Galeão, at the traffic light which controls the left turn. The road surface is in good condition. Average speed at the site is around 60 k.p.h.

The area is commercially active, with auto-parts shops, furniture stores, a drugstore, petrol stations and various services.

Though somewhat complex for an initial training experience, the site was utilized as it allowed a broader adaptation of the observers and facilitated the performing of the subsequent research.

3.2.3 Training the observers

Three engineering students and one traffic engineering technician were chosen as observers. The training consisted of an afternoon of lectures in the theory of the subject and two weeks of practical work. The practical part took place in two stages. During the first week, all the observers positioned themselves at the chosen site and observed the conflicts together. On the first day all four observers worked together. On subsequent days, they worked in pairs, with changeovers, so as to achieve a uniformity of judgement. This uniformity grew as the days passed and by the third visit to the site, the judgements were extremely consistent. In the second week, various conflict counts were performed, just as they would be in research and the practical difficulties, such as filling in the forms, the way to register conflicts, modifications to the form, etc, were discussed.

During both the training and the research a video camera was used to simultaneously register the events observed. The objective of the recording was to be able to resolve any doubts regarding the detection and classification of the conflicts. However, a number of difficulties regarding its use were verified:

- difficulty in locating the camera in a position which gives visibility of the whole intersection (in this case it was only possible to record one of the five principal movements);
- difficulty in fully observing the conflict, due to absence of the sequences prior to and following the event.

There are presently some cameras installed at principal intersections to monitor the city's traffic, and these could possibly facilitate the observation of conflicts.

3.2.4 Data collection

The training (observing conflicts) lasted about 10 hours and data was collected for an hour. The total period (32 hours) in which the researchers were at the site served to provide them with appropriate knowledge of the conditions prevailing there.

Due to the objectives of the research and our own restrictions, the work was performed only in the afternoons. A definitive analysis of the site should also include the morning traffic flow. It should be pointed out that at the locations under study there is heavy movement from downtown to the suburbs in the afternoon, with the inverse occurring in the morning.

On several occasions, there was a conflict every minute. As the observers were taking almost a minute to register each conflict, data was lost on various occasions in the first few days. This problem diminished as the team gained in experience.

3.2.5 Results

In total, the researchers spent about 32 hours at the site (including training, preparation and counting). The total counting period was 3 hours, of which only the final count (1 hr. 05 min.) was performed in perfect accord with the French technique adapted for Brazil.

During the final count, 37 conflicts were registered, the principal types of which are shown in Figure 2: 8 type 1 conflicts, 7 type 2 conflicts, 2 type 3 and 2 type 4 conflicts.

These conflicts are compatible with observations of the site during the period of research and also with two accidents described in the military police reports (of the 7 accident reports analysed, only 3 contained a description sufficient for an adequate understanding of the occurrence, and one of those was on a rainy night).

A road safety analysis, although not an objective of this work, served to illustrate the usefulness of the technique and was consistent with the accident reports studied.

Some of the problems observed, as well as having an impact on road safety, cause interruptions to the flow of traffic, several times a day.

One of the points highlighted by the research team was the mental tiredness caused by giving fixed attention to an anticipated event which generally does not occur. This tiredness, together with other factors, such as pollution and heat, makes prolonged observation difficult. It appeared to us that periods of 1 hour 30 minutes to 2 hours. Would be appropriate, with rest intervals of 15 to 20 minutes. These periods will vary, depending on whether the observer is seated or not, weather conditions, etc.

The choice of the locations for observation was highlighted as one of the most important points to be defined in research of this nature. The location should preferably be high as otherwise large vehicles can obstruct one's view.

One peculiarity of our research was the registering of the models of the vehicles. It may be considered that this is an important check, when there are two or more researchers observing the same point, but it is not really necessary and is very difficult to carry out. The model and colour of a vehicle are details which are lost in an instant, as well as unnecessarily holding the attention of the observer. Classification according to the type of

vehicle (car, taxi, bus or truck), on the other hand, is simple to register.

Finally, it is important to have an observer for each approach. At the site studied, due to its dimension and traffic volume, it would be difficult for one person to observe two approaches.

4 - Conclusions

The two experiments described, though limited, show that the TCT utilized in other countries can easily be adapted in Brazil, with only minor adaptations.

The American technique, used in the first experiment, divides the conflicts into various groups according to the manoeuvre of the vehicles involved and recommends the inclusion of less serious events as relevant conflicts. This last characteristic makes the method more applicable (observing more frequent phenomena) without eroding the validity of its conclusions (given that the conclusions were corroborated by analysis of the site accident records of the previous year). The analysis procedures demonstrated their importance in reaching appropriate conclusions regarding the site.

The work of Guedes (1995) suggests the French technique for Brazil. The principal adaptation suggested is the inclusion of traffic light violations, given their high frequency in Brazil. Field study of this technique confirmed the ease of application and its capacity to reveal the operational problems of a site. The importance of training, to achieve uniformity of judgements among the researchers, was also confirmed.

The scale of severity proved to be easy to understand, in all its applications. It is important to note, however, that 'normal' conflict levels here are perhaps higher than in other countries where this technique has been studied.

In both methods, difficulties were observed in differentiating certain normal driving actions from conflicts. In particular, conflicts involving acceleration and those involving pedestrians were the most difficult and created the greatest divergences among the researchers. In contrast, conflicts defined by sudden braking and lane changes were easily determined.

In general, the applicability of TCT does not mean the direct transfer of the data analysis procedures. Especially, it should be re-emphasized that the normal conflict levels and accident rates per conflict in Brazil are perhaps higher than those observed in other countries.

Further to this work, and regardless of the technique chosen, a calibration study is recommended, in order to determine the normal conflict levels for the main types of intersections existing in Brazil. The possibility of a detailed study on the use of video cameras should also be looked into, given the facility of their installation and their prevalence in modern traffic control systems.

A verification of the relationship between observed conflict levels, the physical and traffic control characteristics of the site and the characteristics of the road users and the traffic itself, is another natural line for developing technique (a field in which the use of organized accident data bases has shown considerable utility).

Figure 1 - The São Paulo intersection - Tabor x Cipriano Barata

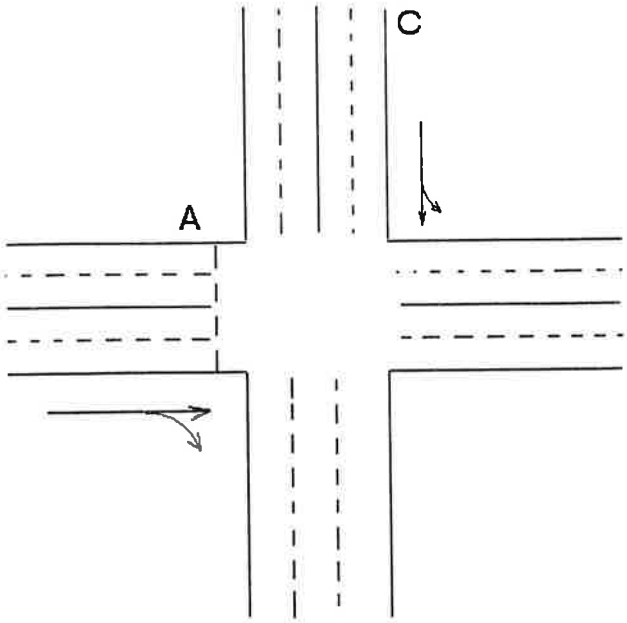
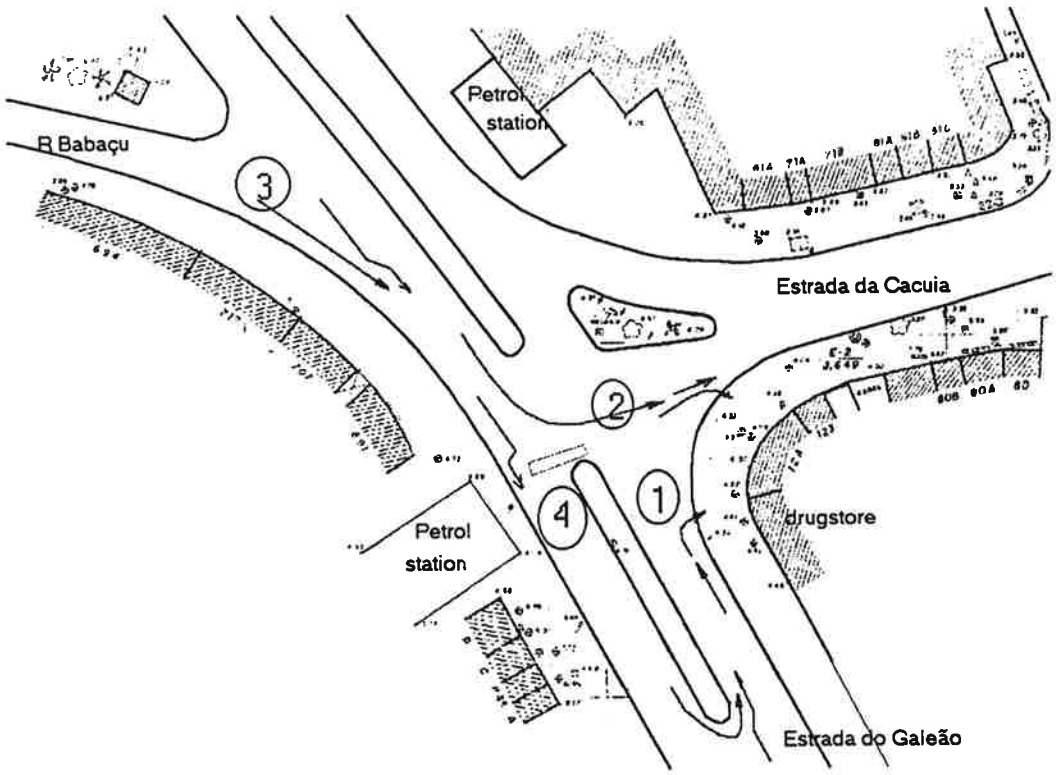


Figure 2 - The Rio de Janeiro intersection - Galeão x Cacuia



5 - References

BRAGA, M. G. C.; RIBEIRO, S. C.; FERREIRA, M. M. (1996). Envolvimento em acidentes e exposição ao tráfego: estudo de caso para a cidade do Rio de Janeiro. Rio de Janeiro (unpublished)

DENATRAN. Departamento Nacional de Trânsito. (1997). Acidentes de trânsito: série histórica 1960-1997. Brasília.

FEDERAL HIGHWAY ADMINISTRATION. (1989). TCT for safety and operations - Engineers Guide.

GUEDES, E. P. (1995). Estudo dos conflitos de tráfego: uma proposta para aplicação no Brasil. MSc Thesis. COPPE. Federal University of Rio de Janeiro.

HYDÉN, C. (1987). The Swedish traffic conflict techniques. Sweden: University of Lund.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. (1996). Anuário estatístico do Brasil. Rio de Janeiro.

MEIRELLES, A. A. C. (1990). Contribuição aos métodos de avaliação de projetos de engenharia sob o enfoque da segurança de trânsito. MSc Thesis. COPPE. Federal University of Rio de Janeiro.

MUHLRAD, N. (1986). Les conflits de trafic ou quasi-accidents: principe et applications. Paris (unpublished).

MUHLRAD, N. (1988). Technique des conflits de trafic; manual de l'utilisateur. Synthèse INRETS, n°. 11, INRETS, France.

OPPE, S. (1985). Contribution to evaluation of intermediate variables: background paper. In: Evaluation 85, Colloque International sur L'Évaluation des Mesures Locales de Sécurité Routière. ONSER. Tome 2, pp. 317-323. Paris.

PIETRANTONIO, H. (1991). Manual de procedimentos para a análise de conflitos de tráfego em interseções. IPT - Instituto de Pesquisas Tecnológicas. São Paulo.

VOLVO. (1993). Programa de segurança no trânsito. Trabalhos vencedores. Brasil.

RISSER, R. (1985). Behavior in traffic conflict situations. Accident Analysis and Prevention, vol. 17, n°. 2, pp. 179-197. USA.

TRL Transport Research Laboratory. (1991). Towards safer roads in developing countries. Crowthorne, UK.

OGDEN, K. W. (1996). Safer roads: a guide to road safety engineering. Averbury Technical. UK.

Title: SAFETY EVALUATION OF RAMP METERING IN GLASGOW, SCOTLAND

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Introduction

As part of the EU DGXIII 'TA*BASCO*' (Telematics Applications in BAvaria SCotland and Others) project, the Technical University of Crete have developed for Glasgow City Council and The Scottish Office developed an integrated urban control strategy. This strategy, known as the IN-TUC strategy, uses ramp metering, variable message signing and urban traffic control to manage a diversion away from the motorway network at times of severe congestion. The overall project objective was to demonstrate integrated control by achieving overall network capacity maximisation. However, ramp metering, being a tool capable to manage the interaction of traffic at the motorway merge point, was seen as potentially offering significant traffic safety benefits. Traffic safety is a prime motivation for transport improvements within Glasgow and it was therefore of primary importance to study the potential impact upon safety of the control tools developed as part of the overall evaluation.

This paper describes the application of ramp metering, evaluates the network effects of ramp metering and develops a safety hypothesis which is investigated using image processing. This paper concerns data collected before the implementation of ramp metering only. A comparison of data both before and after ramp metering will be presented at the ICTCT conference in November 1997.

Glasgow

Glasgow is the largest city in Scotland, having a population of 625,000, within a conurbation of 1.7 Million. It has responded to the decline in traditional heavy industries (e.g. ship building) and adapted to become one of the foremost business centres in the UK, now possessing both a buoyant industrial and service sector. Its success is assisted by high quality transport links to outlying areas. It has an international airport located some 13 Km west of the city centre and is at the heart of the national motorway network. Within the urban area the city is served by a capacious local road network and a comprehensive public transport service, including underground trains. The city and its surrounding area benefits from the largest rail network in the U.K. outside London. The M8, a major east-west motorway connecting Glasgow with Edinburgh and linking to the UK motorway network, passes within 1 km of the central business district. This motorway, whilst providing excellent communication links to the outside world, brings specific problems, particularly in peak periods, when commuting traffic mixes with long distance traffic resulting in conflict and delay both upon the M8 and upon the surrounding road network.

A Changing Transport Policy

It was recognised in the mid to late 1980's that large scale road building was not the answer to Glasgow's traffic problems. Hence, a balanced programme of physical capacity enhancements and the use of ITS techniques was adopted, to make optimal use of the existing road infrastructure and encouraging, where possible, a modal shift towards public transport. The Council's transport policies support wider objectives to improve the quality of life for residents and aid the continued regeneration of the local economy. In following these objectives Glasgow continues to be at the forefront of emerging technologies.

Glasgow City Council are strongly committed to improving road safety and aims to achieve or better the UK Government's national target of a third reduction in casualties by the year 2000. In the past five years Glasgow has seen a 52% reduction in fatal casualties and a 19% reduction in other injuries. The authority are convinced that telematics applications such as ramp metering can make a valuable contribution to this aim.

Glasgow and the Clydeside conurbation has a strong history of involvement in co-operative projects within the European Union, such as EUROCOR (European Urban Corridor Control). Similarly it has a history of innovation within the traffic control field, being the first European city to be equipped with an urban traffic control system, some 30 years ago. It is recognised that a continuing forum for both development and an exchange of ideas is needed if innovation is to be maintained. To this end Glasgow continues to be actively involved in European research, development and project implementation.

Glasgow Within The TA*BASCO* Project

The TA*BASCO* project, involves demonstrations of telematics applications throughout Europe. Glasgow City Council, the project's co-ordinating partner, is actively participating in specific work areas involving Variable Message Sign (VMS) assisted park and ride, BALANCE traffic control to assist public transport through urban signalised junctions, and an urban integrated control strategy that harmonises the interaction between the motorway and urban road networks. This paper concerns the traffic safety implications of the implementation of ramp metering as part of integrated control.

Ramp metering uses the ALINEA control strategy developed by the Technical University of Munich and tested within the DRIVE I CHRISTIANE project, and is located at the M8 junction 16 eastbound on-ramp, figure one. Ramp metering was envisaged, initially, as a solution to a recurring PM peak period problem, but could conceivably be triggered at any time of the day. VMS signs are located on each urban approach to the ramp. When ramp metering is operational VMS on each urban approach advertise the availability of alternative routes to the north and south of the M8 that take traffic to the downstream junction 15. During times of severe congestion or incident the diversion route can be prescribed with the on-ramp signed as closed. Vehicle passage along the urban alternative routes is eased by the selection of appropriate signal plans.

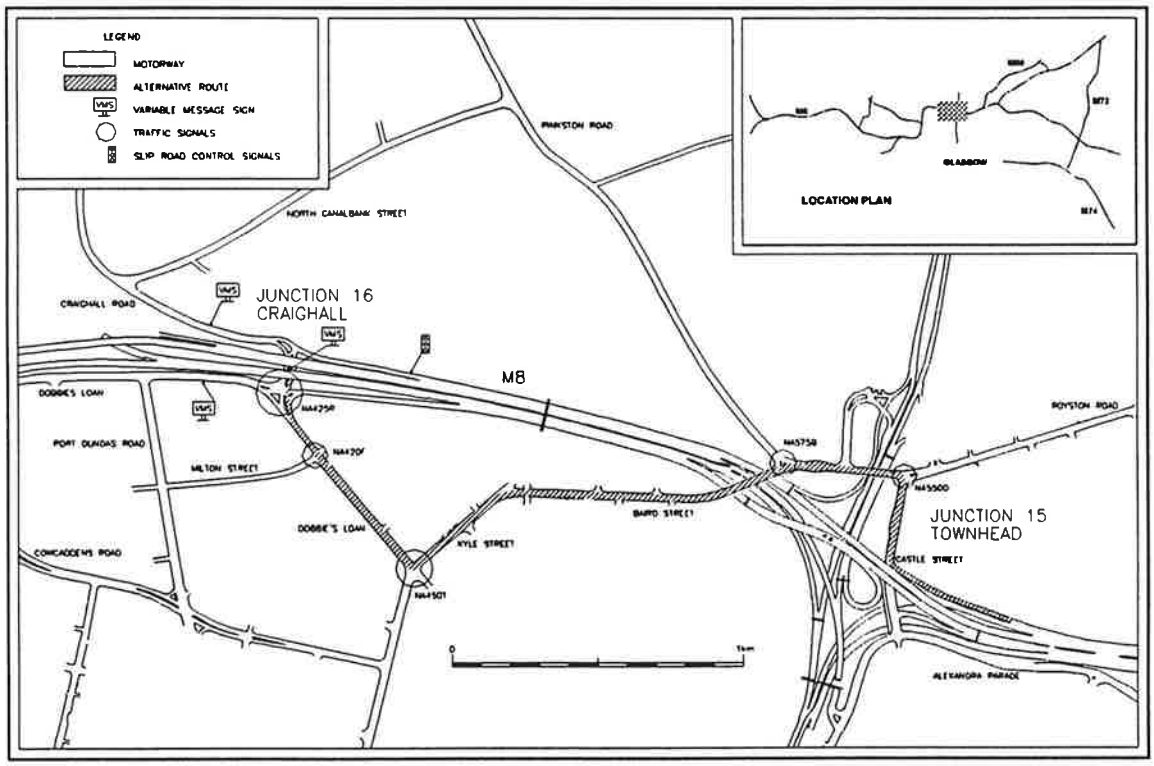


Figure 1: Glasgow Integrated Control Study Area

Evaluating Integrated Traffic Control

It was considered that integrated control should aim to increase network efficiency whilst recognising the potential impacts upon the urban road network and, in particular, the safety and environmental impact upon the road network as a whole.

Evaluation follows the guidelines given by the European Union DGXIII project CONVERGE. These guidelines aim to ensure cross site comparability. Close co-operation with implementation in Lyon and Munich following a common set of objectives aids the demonstration of generic transferability of the control processes developed.

Network Impact

Road impact statistics are produced by analysing detector data collected continuously for both the motorway and urban networks throughout the evaluation period, approximately one year. This involves the storage of approximately 2Gb of data which is first cleaned, then checked and manipulated using an off line database model. Output is in the form of link based statistics relating to vehicular delay, emissions and noise as well as an analysis of vehicle flow characteristics. Motorway detector sites provide flow, speed and occupancy measurements collected at 3 minute intervals. This allows a detailed level of understanding of traffic flow behaviour on a microscopic level to be developed. Flow data on the urban routes is collected at 15 minute intervals. Whilst coarser, it is still detailed enough to provide an accurate assessment of delay characteristics.

Evaluation of ramp metering has shown a significant increase in throughput on the M8. Figure 2 compares before and after ramp metering speed flow curves on the M8 immediately up stream of the controlled ramp. Figure 2 clearly shows an increase in overall capacity and a smoother, more clearly defined, speed flow curve as a result of the implementation of ramp metering. As a result of managed entry to the motorway the incidence and severity of developed shock waves have been shown to decrease.

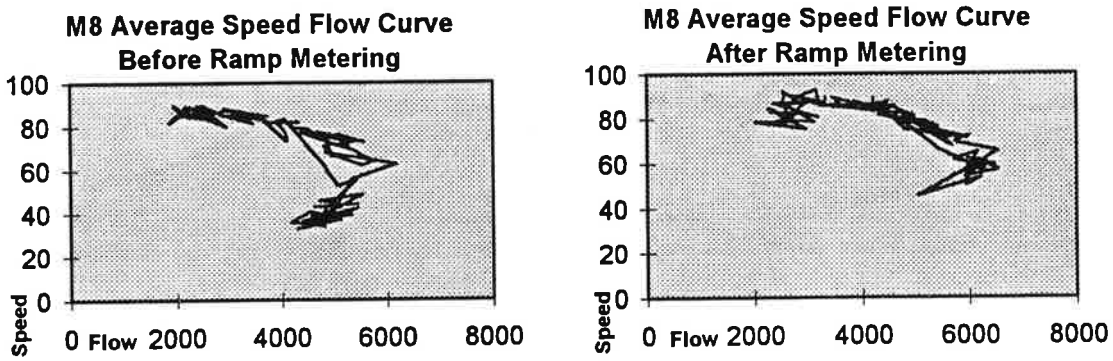


Figure 2: M8 Speed Flow Curves, Before and After Ramp Metering

Considering the network as a whole it has been shown that ramp metering had reduced flow upon the on ramp and had increased flow upon the urban alternative route. As a result of increased traffic levels upon the urban diversion routes, there was a subsequent increase in delay and therefore journey time. Overall however it was found that more traffic was travelling through the network, suffering less delay. A reduction in delay has compensated for the increase in traffic levels ensuring that emission and noise levels remain constant.

Safety Evaluation And A Safety Hypothesis

Road safety is a primary concern of both the Scottish Office and Glasgow City Council and a key motivator in the implementation of motorway lane control as part of NADICS. Within the evaluation period it was considered neither accurate, in terms of statistical integrity, or beneficial, in terms of a true understanding of safety, to consider incident occurrence only as an indicator of safety. In preference conflict analysis was undertaken. This analysis used the UK Defence Research Agency's ASSET-2 image processing software to analyse video footage recorded by CCTV. Video images were used for weekday two hour PM peak periods two weeks before and two weeks after the implementation of ramp metering.

The conflict analysis considered the change in merge behaviour as a result of ramp metering. It was hypothesised that the implementation of ramp metering would enhance the merge of traffic joining the motorway thus reducing avoidance manoeuvres upon the motorway and reducing the incidence of potential collision trajectories upon the motorway. Anecdotal evidence had shown vehicles were merging at a lower speed and using the full length of the ramp in order to select an appropriate merge point. This was considered to be a product of the forced stop and subsequent requirement to accelerate before merging. The improved speed flow on the motorway approach to the slip, demonstrated in figure two, together with a smoother merge was thought to reduce the incidence of breaking and subsequent avoidance manoeuvring. It was considered that these factors would be effective indicators of safety that could be quantified. The indicators of safety were therefore considered to be headway compression and lane switching on the motorway at the merge approach, time to collision between merging and motorway vehicles and point of merge.

The ASSET-2 System

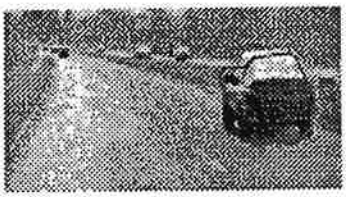


Figure 3: Image Tracking

ASSET-2 is A Scene Segmenter Establishing Tracking - Version 2 developed by the UK Defence Research Agency. ASSET-2 is a complete real-time vision system for segmentation and tracking of independently moving objects. It is a system designed to require no camera calibration or motion registration performing all calculations in the image plane. Information gained from the motion of two dimensional features is integrated with one dimensional boundaries. ASSET-2 achieves automatic instantiation of tracking for each new object detected, and any number of objects can be tracked. Through the accurate tracking of single objects occlusion of one object by another should not be a problem. The temporal integration of segmentation information in such a robust and flexible way is a step forward in the area of image sequence understanding. ASSET-2 starts by tracking 2D image features as they move across the picture over time, to get a sparse image flow field. The flow field is then segmented into clusters which have internally consistent flow variation (using a first-order - six parameter - fit to the flow field) and which have different flow to each other and to the background. The cluster shapes, figure three, are filtered over time to give improved accuracy and robustness. ASSET-2 has been implemented as a real-time system on PowerPC/Transputer image processing equipment.

The Use Of ASSET-2 In Glasgow

In dense traffic conditions, which persisted for much of the filming period, there is little visible roadway between following vehicles, which are moving at similar speeds. This prevents the resolution and tracking of individual vehicles, since the inter-vehicle and intra-vehicle separation of corner points is similar, and frequently results in the segmentation of a large part of the traffic queue as a single object. The problem is aggravated by the fact that very few corner points are detected on the road surface in images from the high mast CCTV cameras, due to the effects of slight defocusing and camera motion, which results in the merging of flow regions corresponding to vehicles in adjacent lanes.

Therefore in order to analyse the data it was necessary to determine and track the motion of corner features, rather than attempting to track individual objects. This required an analysis of the number and velocity of corner point tracks crossing designated trip-wires within the scene, and deriving vehicle counts by assuming an average number of corners per vehicle.

Analysis in such a way prevented the measurement of time to collision values and required the interpretation of headway compression from measurements of deceleration on the approach to the on-ramp.

Lane switching movements were detected using trip wires placed parallel to the lane markings. Vehicle flows were determined using trip wires placed across each lane and lane accelerations estimated from the difference between average speed measurements taken from a pair of trip wires in the same lane.

False triggering by spuriously tracked corner points (which arise from effects of image noise as opposed to a moving object) is reduced by constraining the permissible speed and angle of attack of corners crossing the trip wire. In addition the trip wires are offset from the lane boundaries to reduce the incidence of triggering by vehicles in adjacent lanes which typically occurs when high vehicles obscure part of the adjacent lane.

Merge Analysis Before Ramp Metering

Figure 4 shows the mean speed change on the M8 approach to the on ramp in the 'before ramp metering' period for the two hour PM peak. A positive figure indicates a positive speed difference between a measurement point 30 metres and 90 metres up stream of the on ramp.

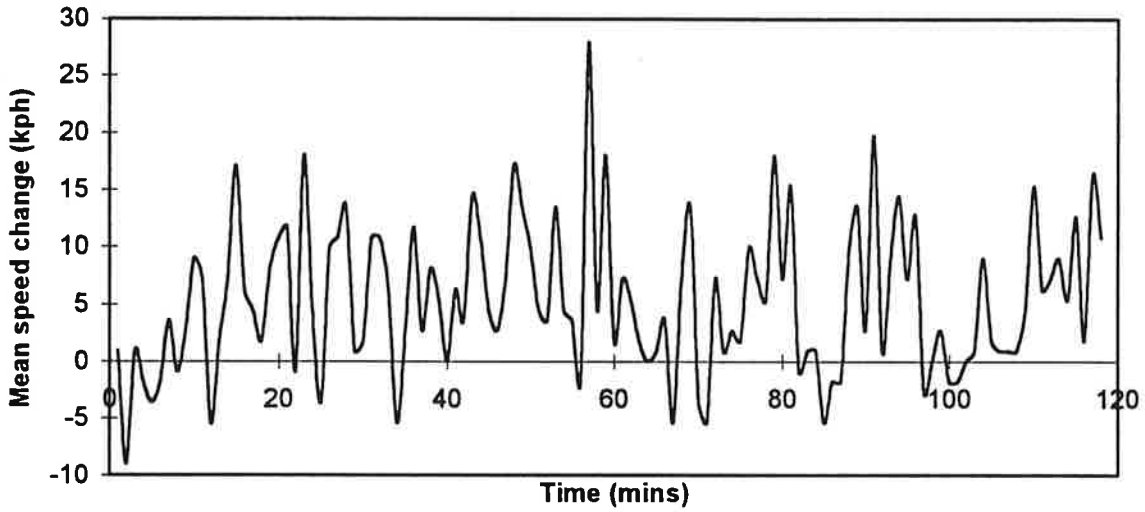


Figure 4: Mean Speed Change on Approach to On-Slip

Figure 4 clearly shows a decrease in vehicle speed on the immediate approach to the on slip caused by the disruption effects of merging traffic. Observation during this period shows substantial shock wave development that reaches to, and beyond, the adjacent up stream on ramp.

Figure 5 compares the incidence of lane switching on the approach to the on ramp at points 30 metres and 150 metres up stream of the on-ramp. From figure 5 it can be seen that the incidence of lane switching increases on the approach to the on-ramp with up to 6 vehicles per minute switching between lanes one and two within 30 metres of the on slip. This would indicate late decision making and avoidance manoeuvres that would add to flow disruption and shock wave creation.

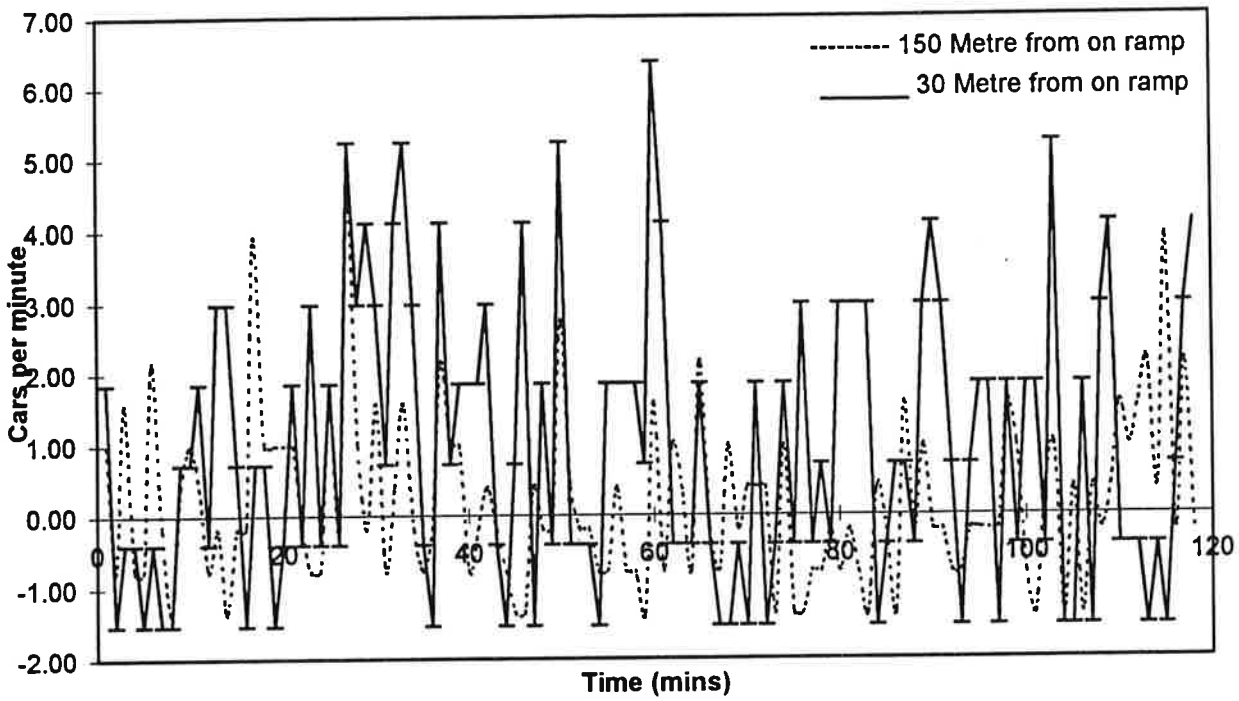


Figure 5: Lane Switching Between On M8 Approach to On Ramp

Figure 6 shows the merge point of vehicles joining the M8. An early merge is defined as a merge that takes place within the first half of the on ramp, consequently a late merge takes place within the latter half of the on ramp. An infringement indicates a merge taking place within the hatching separating the on-ramp from the motorway. Figure 6 shows a reluctance to use the full merge length with significant proportions of vehicles choosing to merge within the hatched area separating the motorway and the on-ramp. This phenomena may be encouraged by low vehicle speed upon the motorway but also may contribute to flow disruption upon the motorway.

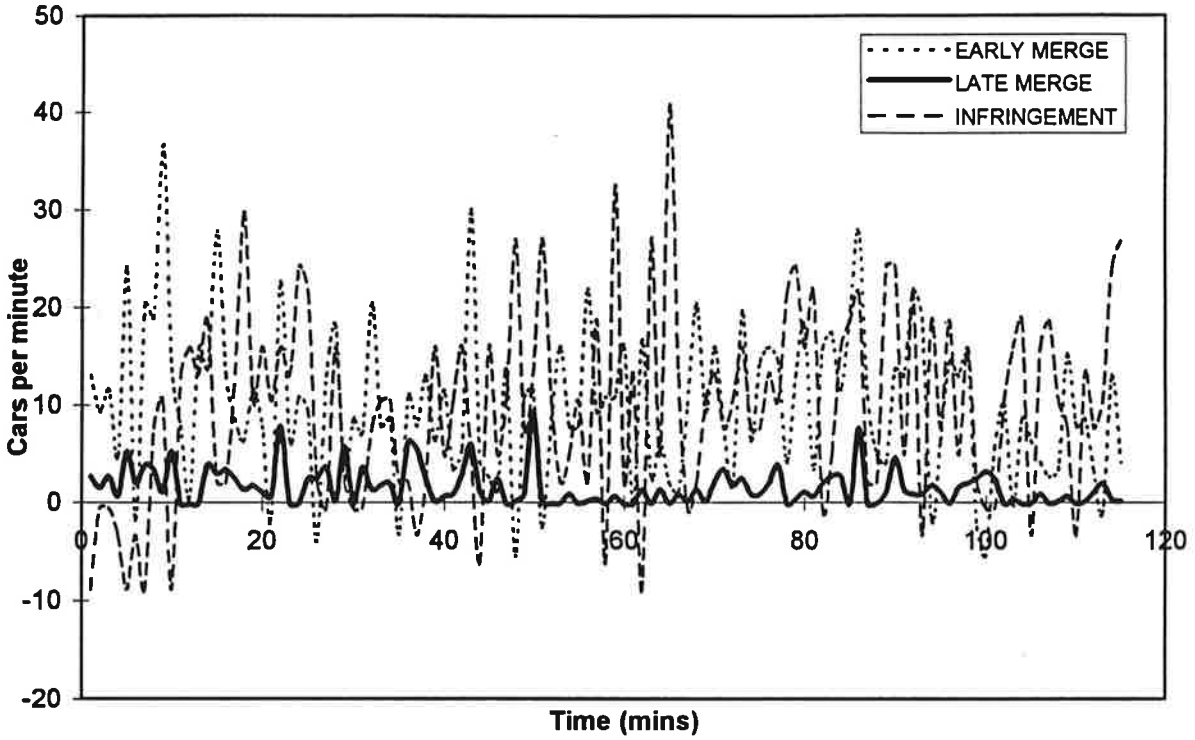


Figure 6: Merge Point of Vehicles Joining M8

Conclusion

This paper has shown how the ASSET-2 image processing system has been used to assess traffic safety on the M8 motorway in Glasgow prior to the implementation of ramp metering. A traffic safety hypothesis has been developed from an examination of the network performance of ramp metering and the ability of image processing to test this hypothesis has been examined. It is considered that ramp metering , by virtue of regulating motorway entry and smoothing the speed flow relationship upon the motorway, ensures optimum use of the motorway merge, reduces the incidence of breaking and avoidance manoeuvres upon the motorway.

The ability of image processing to measure these effects has been frustrated by problems of differentiating between images caused by dense slow moving traffic exacerbated by camera shake and focusing. The latter could be overcome by using dedicated camera positions placed directly above the area of study.

These problems have necessitated the adoption of alternative traffic safety indicators as a proxy for those first derived. An examination of the motorway merge prior to ramp metering has shown that there is a significant decrease in vehicle speed on the approach to the on ramp causing the development of shock waves, that the incidence of lane switching increases significantly on the approach to the on-ramp and that merging vehicles choose to merge early in preference to using the full merge length.

Further work, to be presented at the ICTC conference in November 1997, will compare data traffic safety analysis undertaken before and after the implementation of ramp metering. It is considered that the work described has provided an opportunity to both assess the potential of image processing to provide a measure of traffic safety and the potential safety benefits of ramp metering. This will be have benefits for ramp metering and for other related work, such as microscopic driver reaction to VMS, both within the TA*BASCO* project and elsewhere.

Christoph Hupfer

Deceleration to Safety Time (DST) - a useful figure to evaluate traffic safety? [1]

The traffic conflict technique (TCT) was developed in the fifties in the USA, taken over and modified by other countries. In the origin TCT - without technical equipment - traffic situations were watched by human observers, noted and analysed later on.

The hard criticism of the TCT in Germany led to the end of its systematically use and development in this country. The criticism was related to the bases of TCT and to its usefulness and subjectivity. In a discussion, the criticism of the TCT bases could have been rejected as not established. In addition, the usage and subjectivity could have been modified. But no discussion took place as well as no systematic modification.

Beside the conventional TCT, some techniques have been developed using the improved possibilities of computer technology and the methods of analysing traffic situations. Those techniques are based on objective measurements of physical parameters (distance, velocity, deceleration, direction). The most commonly used objective figures to evaluate traffic situations in relationship to its safety are Time To Collision (TTC) and Post Encroachment Time (PET).

The TTC describes the time distance to a collision of two road users if they keep their velocities and directions. The shorter the TTC the more dangerous is the situation. The TTC can be calculated over the time during the whole traffic situation. There are two values to evaluate the severity of a traffic conflict: The minimum TTC (TTC_{min}) which describes the most dangerous moment during a conflict as the moment of the smallest time distance of the involved road users. The TTC at the moment when an evasive action starts is called Time to Accident (TA). The differentiation between light and severe conflicts is usually defined as 1.5 seconds (TTC), or in relationship to a conflicting speed (TA).

The calculation of TTC needs a collision course which means, that the involved road users will be at the same place at the same time if they keep their velocity and direction. If the road users will miss

[1] This paper is based on a study made at the Transportation Department of the Kaiserslautern University, supported by the Stiftung Rheinland–Pfalz für Innovation (foundation for innovation of Rhineland-Palatinate)

each other by even a small time gap, there is no TTC to calculate, although the situation can not be declared as a safe one.

This insufficiency will be compensated by the Post Encroachment Time (PET). The PET is defined as the period of time from the moment when the first road user is leaving the conflict area[2] until the second road user reaches it. The size of this time gap is proportional to the unsafeness of the observed traffic situation. The border between light and severe conflicts is usually defined as 1,0 seconds. The PET can principally[3] be calculated during the whole situation. Usually, the last calculable PET (lastPET) is taken as figure to evaluate traffic safety. This is the moment, when the first road user leaves the conflict area.

Both figures (TTC and PET) consider "only" whether a collision occurs or not and how close. The necessary intensity of an evasive action to avoid a collision is not considered. Different situations can cause the same TTC, even if in one situation the driver only has to take the foot from the gas pedal and in an other situation an emergency breaking is necessary.

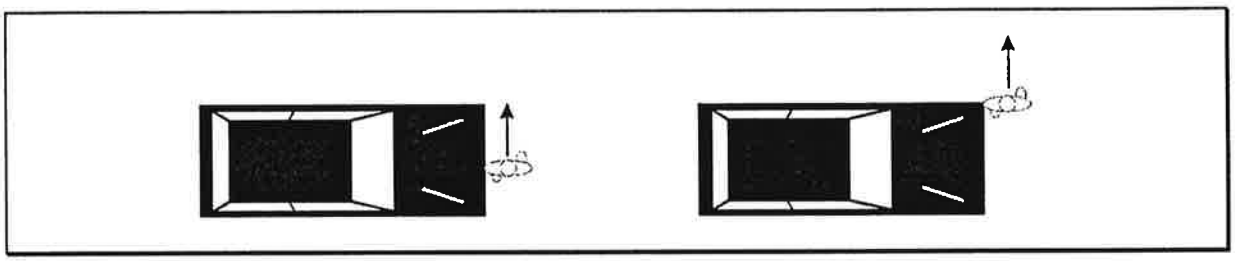


figure **Fel! Okänt växelargument.**: Identical TTCs at different prognosticated positions of a potential collision will require different evasive actions

During a traffic situation only TTC **or** PET is calculable at one moment. Obviously, the course of a safety describing figure has no "jumps" during a traffic situation. Using TTC and PET causes some gaps in the figures during the situation if there is no collision course at some moments.

The TTC describes the time to a critical situation (collision), PET relates to the result of a situation, regardless of the time until it occurrs. If e.g. the PET will amount to 0.5 seconds by unchanged velocities and directions, but the first road user will leave the conflict area in 5 seconds, the time distance of the second road user to the conflict area will be 5.5 seconds. This is time enough for an evasive action. The TTC of 0.5 means that a collision will occur in 0.5 seconds. There is no time for a controlled evasive action. In both cases the safety figure has a critical size without the same critical situation in reality.

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[2] Assumption: both road users involved in an encounter keep their velocities and directions
[3] PET is only defined if there is no collision course

The analysis of video recorded conflicts during pedestrian crossings[4], TTC_{min} and lastPET sometimes showed critical (dangerous) values without any occurrence of a hazardous situation in reality.

These were the main reasons for an approach to evaluate traffic safety according to the necessary intensity to avoid a collision or to reach a safe time distance in the end of an encounter.

The necessary deceleration[5] to reach a last calculable PET ≥ 0 is defined as **Deceleration to Safety Time** ($DST_{t_{safety}}$). The index t_{safety} belongs to the chosen time distance (last PET) which has to be reached for a safe encounter.

The calculation of DST refers to the position of the first road user[6], as he leaves the conflict area. The second road user may reach this point not earlier than the first road user leaves it (PET=TTC=0 → DST_0).

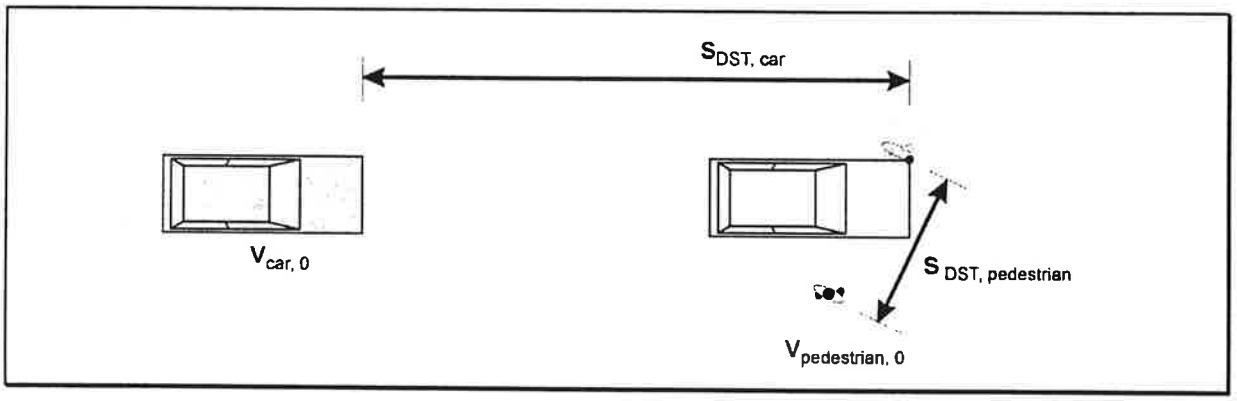


figure **Fel! Okänt växelargument.**: values to calculate DST shown on a pedestrian–car–conflict ($v_{pedestrian}$ = $v_{pedestrian,\,0}$ = constant, v_{car} ≠ constant)

For $v_{car} > 0$ and $v_{pedestrian} > 0$ is valid

$$t_{DST_0} = \frac{s_{DST,pedestrian}}{v_{pedestrian,0}} \overset{!}{=} \frac{s_{DST,car}}{v_{car,0}} \qquad v_{Kfz,0}, v_{Fg,0} > 0$$

$$s_{DST,car} = v_{car,0} \cdot t_{DST_0} + \frac{a \cdot t_{DST_0}^2}{2}$$

$$-a = \frac{2 \cdot (v_{car,0} \cdot t_{DST_0} - s_{DST,car})}{t_{DST_0}^2} = DST_0 \left[\frac{\mathrm{m}}{\mathrm{s}^2}\right]$$

For a required safety time distance of x seconds the DST can be calculated in general as

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[4] more than 6.000 recorded pedestrian crossings, 3.400 have been analysed by using PET and/or TTC
[5] taken as the main evasive action
[6] First road: The road user who reaches the conflict area first.

$$t_{DST_x} = \frac{s_{DST,ru_f}}{v_{ru_f,0}} + x = \frac{s_{DST,ru_s}}{v_{VTs,0}} + x \qquad v_{ru_f,0}, v_{ru_s,0} > 0$$

$$s_{DST,ru_s} = v_{ru_s,0} \cdot t_{DST_x} + \frac{a \cdot t_{DST_x}^2}{2}$$

$$-a = \frac{2 \cdot (v_{ru_s,0} \cdot t_{DST_x} - s_{DST,ru_s})}{t_{DST_x}^2} = DST_x \left[\frac{\mathrm{m}}{\mathrm{s}^2}\right]$$

ru_f : road user who reaches the conflict area first

ru_s : second road user

The use of DST shall be shown on the following example of a pedestrian crossing. The crossing person adapts his behaviour to the behaviour of the car driver. At first, he wants to cross behind the car and decelerates a little to give the right of way to the car driver. The car driver decelerates too, so the pedestrian crosses in front of the car.

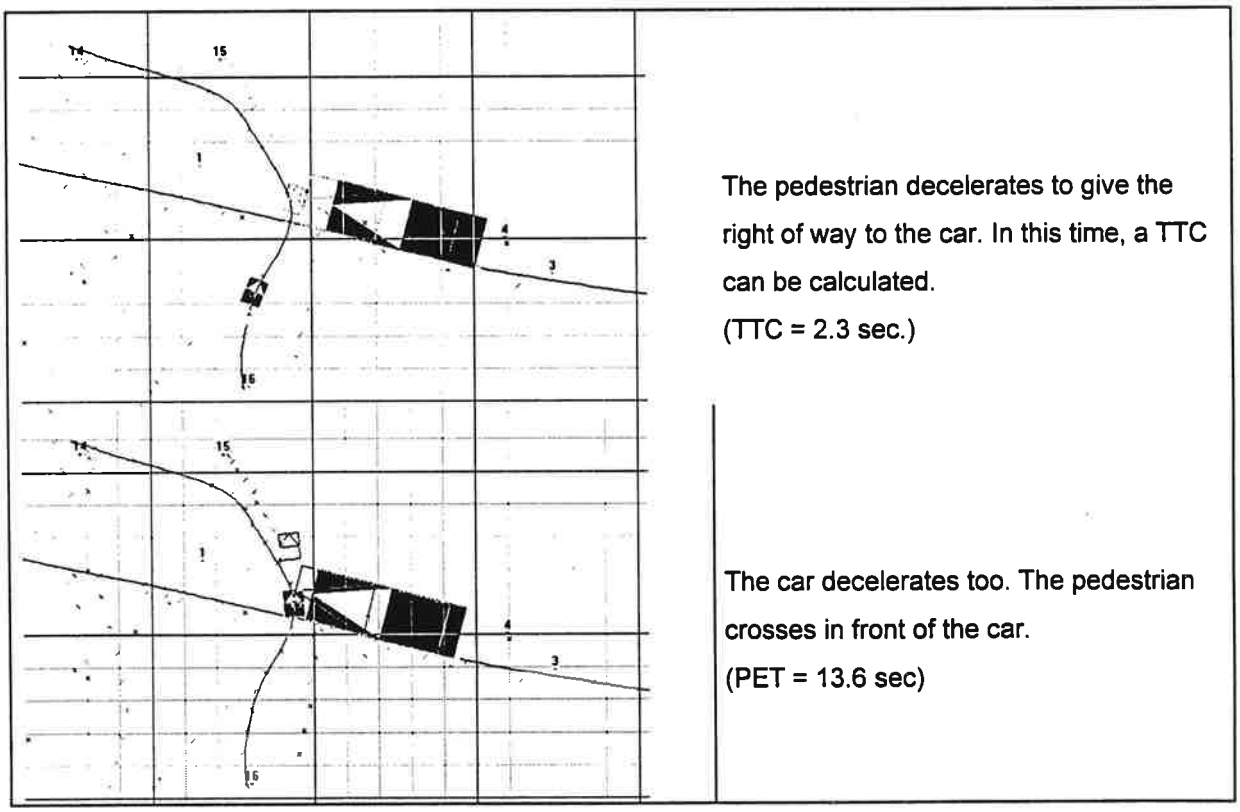


figure **Fel! Okänt växelargument.**: A pedestrian crossing visualised with an analysis tool. A filled box shows the actual position of a road user, an outlined box the predicted position by unchanged direction and velocity at TTC or PET. Both road users are slow.

The adapting behaviour is continuous shown by the DST_0 curve. The road users are moving on the border lastPET = 0. First there is a big PET, but when the pedestrian decelerates, it comes to a TTC

less than 1.0 second. The DST (maximum 0.3 m/s²) detects no dangerous moment during the situation, the TTC_{min}, of course, does.

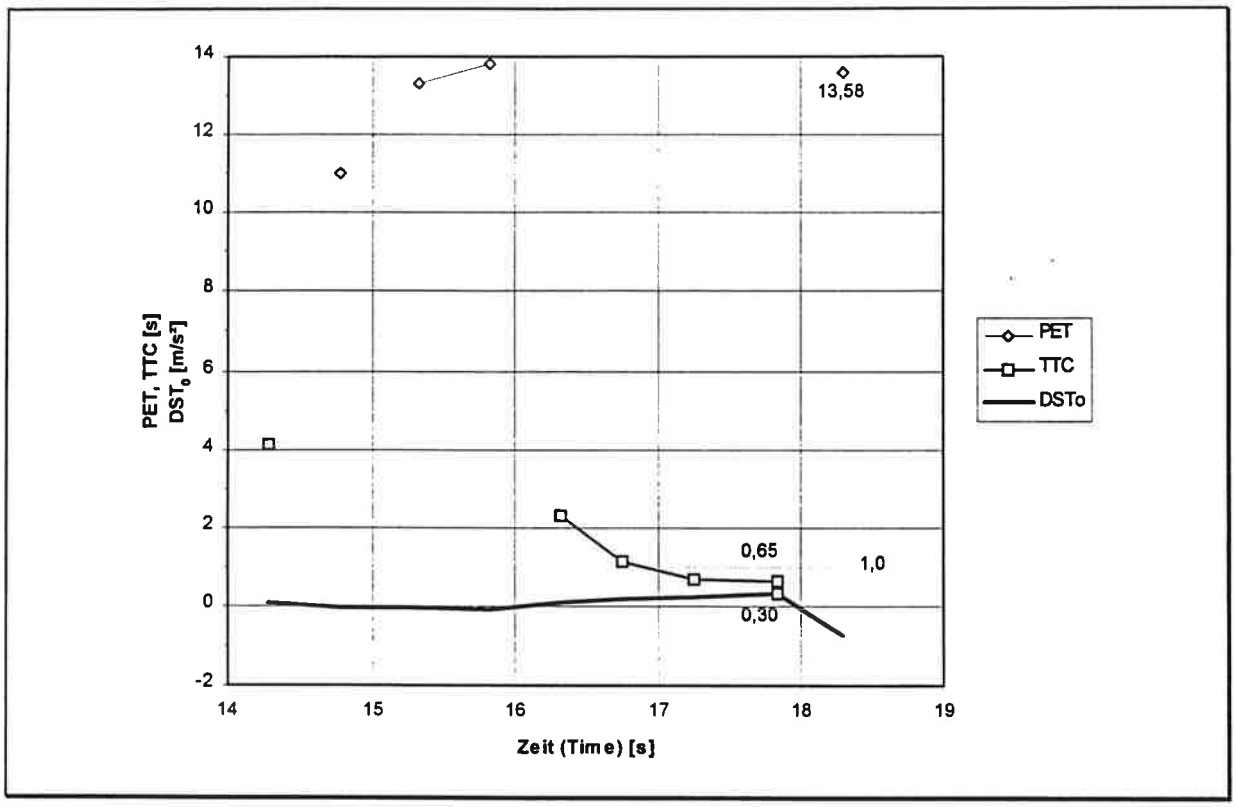


figure **Fel! Okänt växelargument.**: conflict values during a pedestrian crossing

The DST can be calculated for each moment of a traffic situation. It is positive (deceleration is necessary) if there is a collision course or a calculated PET < x, otherwise it is negative. The maximum DST gives an idea of the safety of a traffic situation.

The DST can be modified to various demands of safety (a safe situation maybe reached with a PET of 1 second → x=1) and various surrounding parameters (on a dry road are bigger decelerations possible than on a wet one).

DST gives the possibility to define the severity of a conflict following the conventional TCT:

$DST_x \leq 0$ m/s²:	Evasive action not necessary The predicted/reached safety time distance is bigger than *x*, an adaptation is not necessary.
$DST_0 < 1$ m/s²:	Adaptation necessary (interaction) The necessary evasive action is small, only a light adaptation has to be made.
$DST_0 < 2$ m/s²:	Reaction necessary (Conflict Level 1) The situation requires a noticeable deceleration of a road user. The situation is easy to control. There is time enough to consider other occurrences.
$DST_0 < 4$ m/s²:	Considerable reaction necessary (Conflict Level 2) The situation requires a considerable deceleration of one road user. The situation is controllable. Other occurrences can not be easy considered. (On a wet road this might be the maximum possible deceleration and is similar to an emergency breaking: Conflict Level 4)
$DST_0 < 6$ m/s²:	heavy reaction necessary (Conflict Level 3) The situation requires a heavy reaction of at least one road user involved in the conflict. The reaction is hardly controllable. Other traffic occurrences can not be considered.
$DST_0 \geq 6$ m/s²:	Emergency braking (Conflict Level 4) Uncontrollable reaction. Near miss accident.
Collision	

figure **Fel! Okänt växelargument.**: Suggested Definition of Conflict Levels under the use of DST according to the conventional TCT

A comparison of TTC, PET and DST in more than 3.400 situations was made by studying the safety of pedestrian crossings at different locations with different traffic parameters. The DST proved to be a reliable instrument to evaluate traffic situations in relationship to its safety.

For the analysis of the road user motion lines, their courses were detected as a polygon out of their positions in succeeded video pictures and rebuild as a mathematical function to calculate distance, velocity, direction and acceleration at each moment. This can be designated as a half automatically TCT. With the realisation of an automatically detection of road user positions out of video pictures by computers, a fully automatically TCT is possible.

Questions regarding the relationship between the number of light conflicts and its effects to traffic safety as well as how to handle the prediction of conflict values in curves (main base of TCT: direction unchanged) could not be answered. This has to be the aim of following studies.

Nevertheless, one result of the study was again, that video based Traffic Conflict Technique is a very helpful tool in traffic safety work - also in complement to accident analysis.

Study of Traffic Accident Mechanism by Automatic Recording System(TAAMS)

Applications of TAAMS for signalized Intersections and Visualization of TAAMS Images by 3DCG Technique-

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National Research Institute of Police Science, Japan

ABSTRACT

Automatic recording system (TAAMS) was improved for signalized intersections, which has additional devices for detecting and display the states of signals when an accident occurs as main functions. Video pictures (40 or 80 flames) including just before and after accident or near miss phenomena can be recorded by the TAAMS. The TAAMS were installed on the six intersections with and without signalized intersections with different sizes, and field trails were carried out for 30 months from 1994. The TAAMSs have been worked without interference with the continuous operation of the traffic signals. Approximately 150 accident cases and a lot of number of near miss phenomena were recorded. The data were analyzed to assess the implications for driver behavior. In accident investigations particularly at signalized intersections, the images of TAAMS were employed to elucidate implications in state of signals and the driver behaviour. The results are concluded that the TAAMS data helpful for investigators because of providing some fundamental information such as locations of vehicles relations to the state of signals at the accident, their velocities, a collision point, etc.. In addition, applications of 3 dimensional computer graphic technique (3DCG) will be also discussed for study of accident mechanism using TAAMS image data in this paper. When and/or under what specific situations drivers in pre-accident stage had misjudged are discussed with driver view fields through the animation generated by 3DCG technique.

1. INTRODUCTION

A key to the solution of traffic accident mechanisms at intersections with signals is its relation with states of signal before and after accidents. However, reliable information cannot always be collected because many people involved with accidents do not clearly remember the color of the signal shortly before the accident and are afraid of being condemned for the fault of the accident itself. This paper describes the display function of a state of signal which was added to the Traffic Accident Auto-memory System (TAAMS)[1],[2] as well as results from a field test. This paper also reports the application example of preventing recurrence of similar accidents by improving a road marking at an intersection based on results of video data analysis and reviews the possibility of TAAMS for traffic engineering.

On the other hand, many factors are

associated with traffic accidents, but over 90% of causes is due to human factor according to both UK and USA reports[3]. Particularly, it is common saying that the main cause of cross accidents at intersection is attribute to error of cognition or misjudgment on safety.

In research on decision making of drivers, there have been very few instances in which actual vehicular behavior in accidents has been recorded. In the study of these assumptions, we have analyzed vehicular behavior immediately prior to accidents employing data from TAAMS(3),(4) and studied the contributory factors which have affected the decision making of drivers. TAAMS data is, however, second dimensional image, it is difficult to discuss visually of intersection through driver's views, while the 3DCG technique in computer is convert from the images of two dimensions to of three dimensions. Using 3DCG technique it is easy to produce the images from different views such as drivers' view fields. For example, we can examine through the 3DCG images whether the driver on the minor road can look the vehicle running on the major road from the stop line or not.

2. METHOD

2.1 Outline of TAAMS

Figure 1 illustrates configuration of TAAMS improved for signalized intersections (2 camera type). The cameras and microphones are mounted above the intersection, where the camera field of vision includes the junction approaches (approx. 25m), and the junction itself. The memory unit continuously stores the image and sound collected through camera and microphone from the intersection. The VTR recorder is activated by the sound discriminator. When activated the VTR recorder takes either forty (or 80) pictures at normal speed of 1/10 second. The system then automatically resets for next actuation. It is claimed that one 120-minute videotape can store details of approx. 1,000 (or 800) cases.

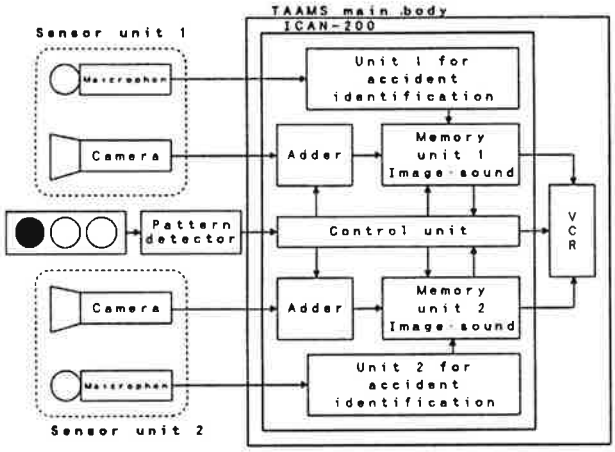


Fig.1 Schematic of TAAMS

2.2 Function of Detecting Signal State

Figure 2 is a configuration diagram for detecting states of signals. A current sensor is attached to the cables of signals in the signal controller and the flow of electricity in each cable is detected without contact. TAAMS converts this detected electricity first to parallel state signals, then to RS-422 signals and distinguishes the combination of lighted signals and adds the name of the step to the video data.

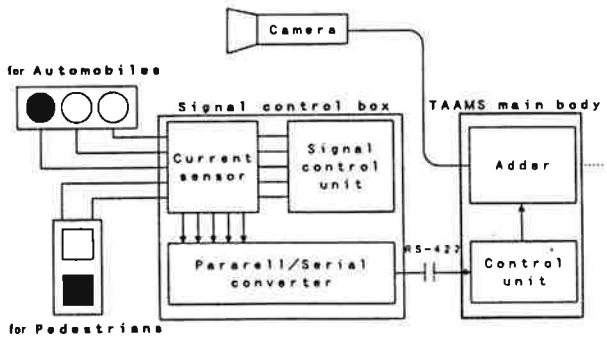


Fig. 2 Schematic functions of detection and display for states of signal.

2.3 Performance Test of TAAMS

Three systems of TAAMS, with additional functions of detecting states of signal, were experimentally installed at three signalized intersections of different scales such as a small, regular and large scale, respectively. The field tests were completed with cooperation of the Metropolitan Police Office. Figures 3 and 4 show a plan of the large scale intersection, and the signal step table used in the intersection, respectively.

Plan of Signalized Intersections

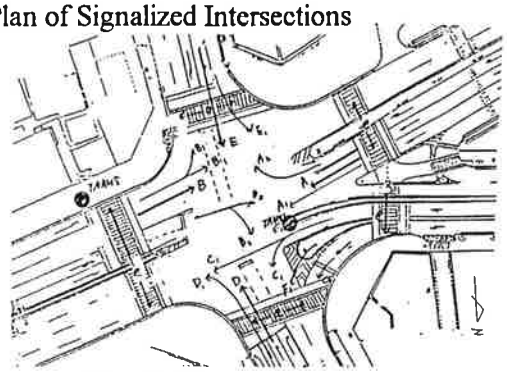


Diagram of Signal Steps

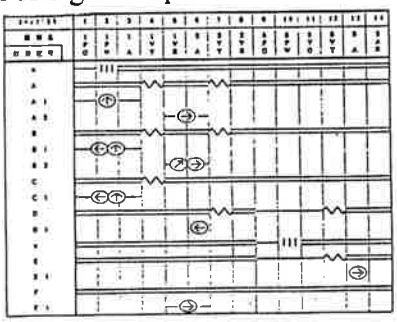


Fig. 3 An Intersection with Traffic Signals.

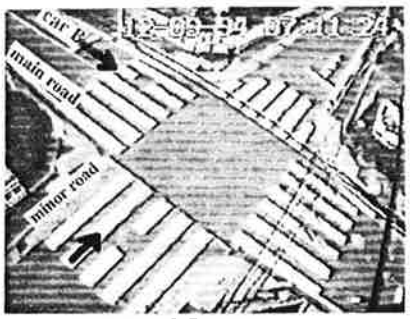
For the field test of automatic recording function on TAAMS, commercial 120-minute videotapes were used and were replaced every one month. An analytic study of the recorded video data was conducted. Performance tests on detecting and display states of signal were also carried out through conducting continuous recordings in the field, with the automatic detection function of video data tentatively turned off, using commercial 210-minute videotapes in a triple-speed recording mode (recorded 10.5 hours/one tape).

2.4 Application of 3DCG Technique

The PRISMS 3D[4] animation system is a totally integrated software package, components: stage, action, ice etc., from which animation can be produced on workstation computer such as Indigo by Silicon Graphics Co.. In the production of 3DCG animation, a hardware, software and video system are used as follows. For hardware Indigo2 Extreme (Silicon Graphics-Cray Co., Ltd.) with CPU R4400, memory 128 Mbytes, Disk 6 GBytes, and for software 3DCG PRISMS (Side Effect Software Co., Ltd.) and PVW2800 (Sony Co., Ltd.) are used mainly, respectively. The basic procedure of 3DCG images and animation generated is as follows.(1) The 3DCG image of the intersection is constructed basis on TAAMS data and geometric data of the site of intersection within the computer. (2)Camera position of TAAMS is calculated by the computer, and the viewpoint of the image is set up at the camera position. (3)Vehicles involved in accident are incorporated in 3DCG image data. And then vehicles are loaded according to the tracks calculated previously, the each original 3DCG image are produced in order.

2.4 Intersection without Traffic Signals

Figure 4 shows one of the unsignalized intersections, which have informal priority rule in Japanese traffic law. One roadway represented is regulated with stop sign and pavement marking with stop line on the pavement. On otherwise, the cross way to the way with stop line might be priority (right-of-way), but all vehicles must yield before entering the intersection. Therefore, the roadway with stop sign has poor priority (informal minor road), and the crossing way on it has rich priority (informal major road).



TAAMS Image

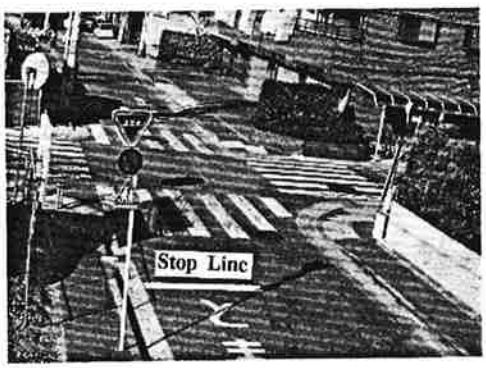


Fig.4 An Intersection without Traffic Signals.

2.5 Intersection Image by 3DCG

Figure 5 illustrates the solid model of the intersection installed TAAMS from different viewpoints constructed by 3DCG technique. The model of the intersection is rendering images at full resolution as similar views of shown in Figure 4, it would be resemble enough detail to the intersection.

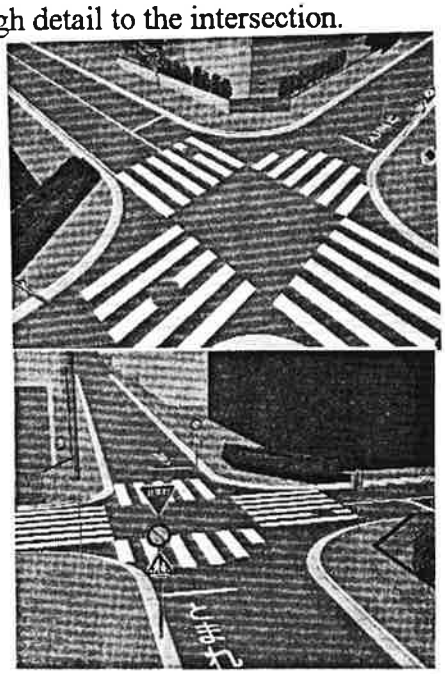


Fig. 5 Solid Image of Intersection constructed by 3DCG technique.

Using the images on computer screen, it is possible to examine the view obstructions through driver's eye views, for example we can investigate whether the driver running major road when he had loaded an emergency brake could see or not the vehicle on the minor road.

3. RESULT

3.1 Results of Tests for Signal States

The function of detection for signal states was determined to have not affected the control of the normal signal function at all. As for accuracy of signal states, analysis of video data recorded by continuous recording mode (with the automatically detecting accidents function tentatively turned off) confirmed that TAAMS completely detected and recorded accurate signal situations.

Figure 6 illustrates an example of traffic flows randomly picked out from continuous recorded video data by TAAMS. It shows that the symbol for signal step in each picture (1) is according to the order specified in the step table and (2) can logically and fully explain the traffic flow at the time according to the situation of states of signal (symbols of signal steps). This Figure 6 demonstrates that signal states were accurately detected and displayed.

3.2 Accident at Signalized Intersection

Figure 7 shows scenes of car crash between a passenger car going straight and a box car turning to left, which occurred at the intersection shown in Figure 3. The signal state (1PG) indicates that the crosswalk in upper right of the picture was at a "green" step. This means "green" for the passenger car going straight and "red" for the car turning to right, so the box car which turned to the right

crossing vehicular behavior at unsignalized intersections.

The driver running on the minor road was induced illusion by vehicular behavior on major road, which was stopped in front of him. At least, it is inferred that his vigilance level at preparing stage would be affected by the vehicular behavior of other oncoming vehicles. In circumstances immediately prior to accidents, the illusory safety judgments of drivers predominate in unsignalized intersections, and are found to be directly related to the causes of accidents.

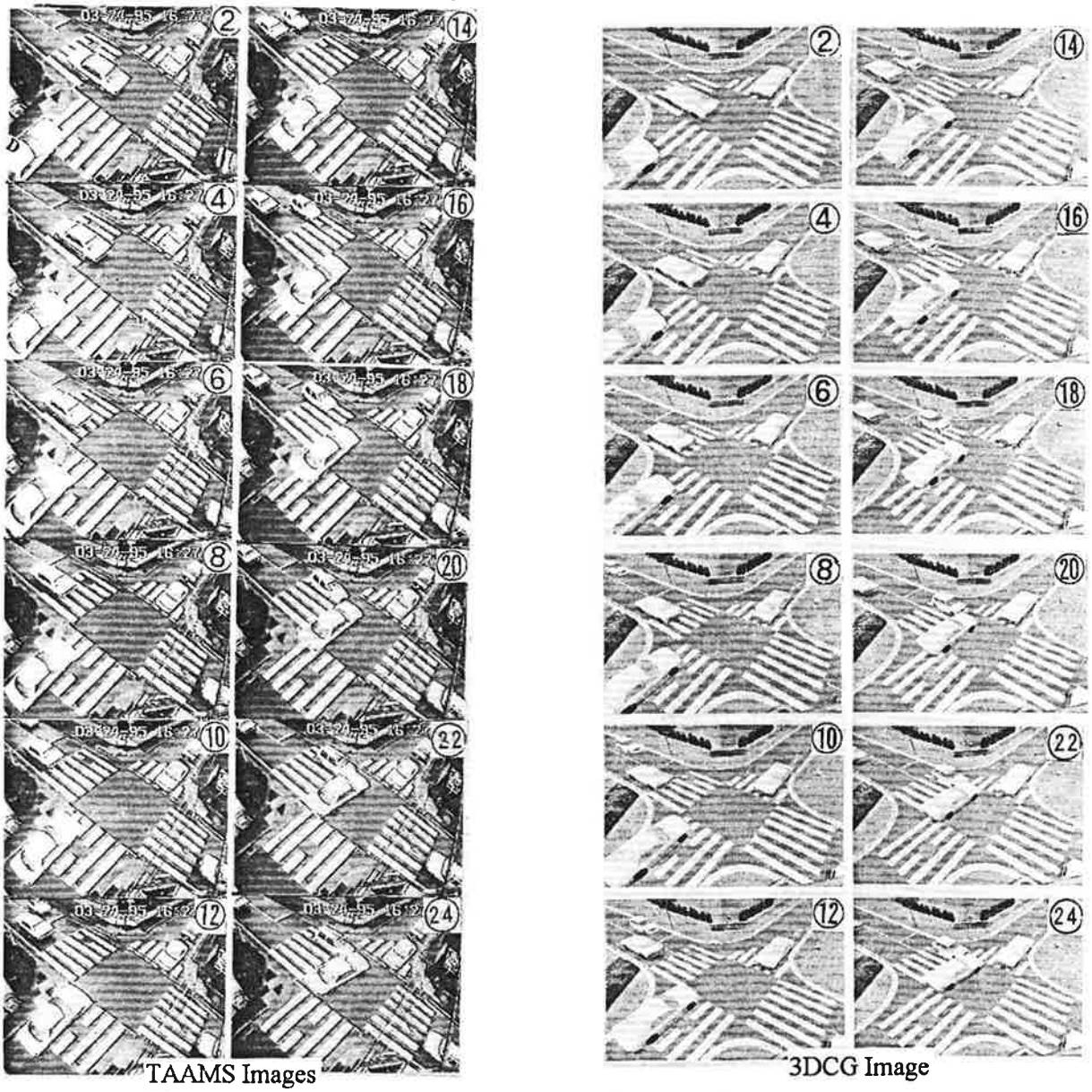


Fig.11 Accident Scenes at Unsignalized Intersection by TAAMS and 3DCG.

Figure 12 shows the results of analysis of the speeds vs. times of vehicles. Vehicle C on the major road passed the intersection at about 20 km/h. Vehicle D was following to vehicle C at low speed. Vehicle A on the minor road to allow vehicle C to pass the intersection first, which was approaching the intersection at an extremely low speed of about 5 km/h. This behaviour indicates that vehicle A either stopped at the Full Stop line or had reduced speed extremely for safety. Furthermore vehicles E and F, on the opposite

side of the thoroughfare, were waiting at the pedestrian crossing and at the Full Stop line for vehicle C to pass through the intersection.

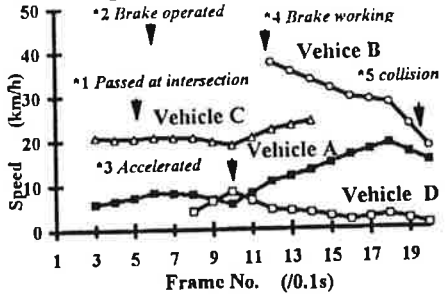


Fig.12 Speed vs. Time.

In other words, driver of vehicle A seem to be a careful driver as same as drivers of vehicle E and F as shown in this manner. However, as shown in Figure 4, driver A increased speed from 5 km/h to 20 km/h to cross the intersection immediately after the vehicle C passing, whereas vehicles E and F stile stopping. At this time, what he had to check was oncoming vehicles on crossing road from both sides of the left and right of him.

Why did driver A make decision to cross the intersection at that time? What did him make decision to do? He have misjudged certainly at preparing stage. It is inferred that he was induced illusion by mainly the vehicular behaviour of vehicle D, and also vehicle C. The behaviour of vehicle D stopping performance affected driver A's judgment on cross particularly, he would understand the situation that driver D gave the way him by stopping action. However, one more important safety checking was remained him, that is, exit of oncoming vehicle from the left on crossing road.

Figures 13 and 14 show the four scenes, which is TAAMS data and 3DCG images, respectively, when the something events observed in the approaching, preparing and crossing stages in Figure 11. Figure 13-A indicates the respective positions of all the vehicles immediately after vehicle C crossed the intersection (Frame 5 in Figure11). Vehicle A was on the pedestrian crossing and was just prior to deciding to cross. On the crossing line, vehicle D to the right of vehicle A appeared on the screen approaching the intersection. However the vehicle "vehicle B" approaching the left side of vehicle A has not yet appeared on this scene as shown in Figure13-A.

Figure 13-B(14-B) illustrates the respective positions of all the vehicles when vehicle A increased his speed to cross the intersection (Frame 9 in Figure11). Vehicle B oncoming toward intersection was on the scene at approx. 13m away from the intersection. And in Figure 13-C(14-C) vehicle B was approx. 10m away, it was loaded brake for avoid a collision with vehicle A. But driver A has increased the speed at that time already. Figure 13-D(14-D) represents the scene when both drivers of vehicle A and B could be seen each other because of vehicle C running away from the intersection. During scenes shown in Figures 13-B and 13-C driver A could not see vehicle B because of obstacle by body of vehicle C.

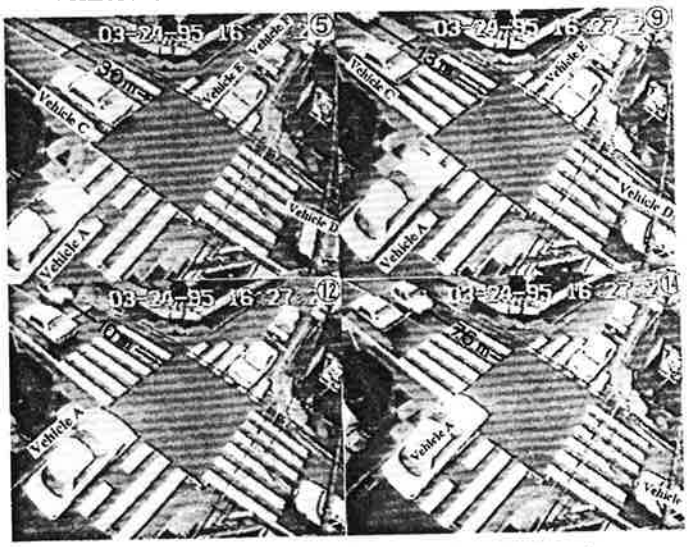


Fig.13 Event Scenes refer to Driver behaviour.

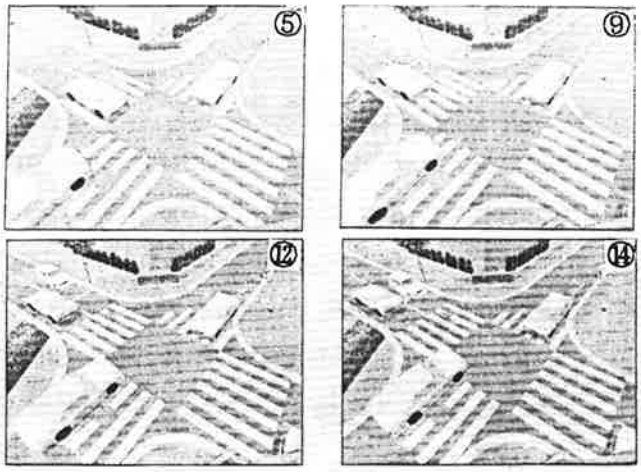


Fig.14 3DCG Image refer to Driver behaviour.

The animation was generated enable the viewers to see the scene in the true perspective from any chosen viewpoints using the original images.

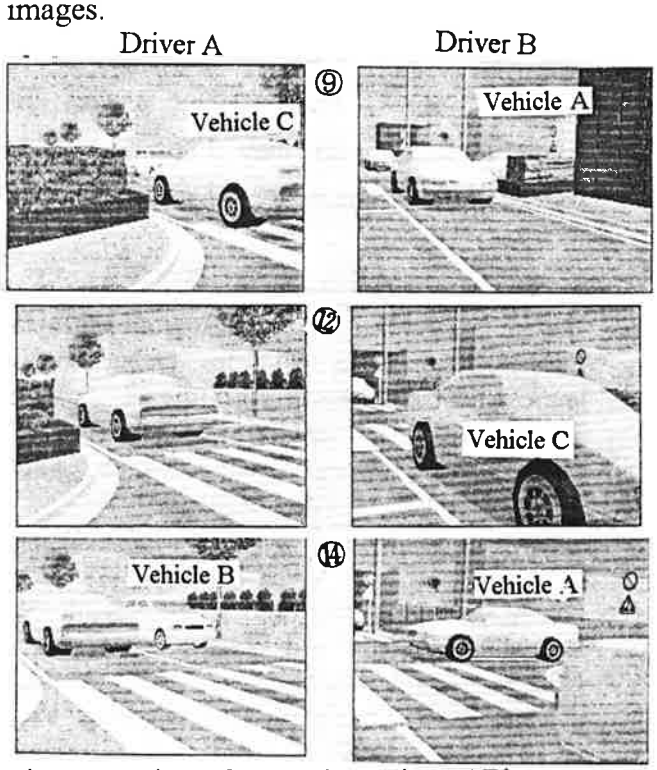


Fig. 15 Views from Driver A's and B's Eyes.
(at Frame No. 9, 12 and 14)

When the animation as three dimensional images is once generated in the computer by 3DCG technique, it is able to relative easy modify according to specific conditions. For example, views from driver A eyes on preparing and crossing stages as shown in Figure15 as models of the visual images for practical tool using the traffic accident mechanism. He could not see vehicle B approaching to the intersection mostly time, except only (as shown in Figure 15-B) an instant, because of obstacles by body of vehicle C. The animation is informative means to instruct why drivers make misjudgment or what make him decision at approaching and/or preparing stage in the intersections.

5. DISCUSSION

5.1 Application for Signalized Intersection

TAAMS data suggest a clear relation between the state of signal just before an accident and the driver's action (horn, emergency brake, etc. for example) by analyzing the video data and traffic sounds that were recorded by TAAMS to effectively study the mechanisms of accidents at intersections with signals. Therefore, new classification methods would be possible, which are different from traditional methods using the results of these traffic accidents, inclusive of classification, by focusing on factors which may cause accidents from the intent of preventing them.

5.2 Application of 3DCG Technique

In this paper, an traffic accident mechanism as a model by TAAMS data and modified image using 3DCG technique is offered and discussed, for examples, as shown in Figure 10 through the driver's eye views are very informative. The images was used to explain and confirm that driver views such as when he decided to cross the intersection. It is concluded that he decided to cross intersection in spit of impossible seeing vehicle B oncoming toward intersection by obstacle of vehicle C passing just before.

In the example, the drivers on the minor

road ware regarded as careful driver, because who decreased approaching speed enough such as around 10 km/h. This fact suggest that they never ignored the crossing vehicles in the approaching stage. In the preparing stage to cross intersection, they only judged the situation was safe. The problem is why they judged the situation safe in spite of oncoming vehicle on cross road.

Why did not he check to the left to look for vehicles oncoming? Probably, he judged the situation was completely safe because vehicle D was stopping in front of him. But what driver D did was only to avoid collision against vehicle A, it doesn't mean to compensate that vehicle A could cross the intersection at that time.

But driver A only paid his attention to cross the intersection. What made him neglected to check safety? At least, this case suggest that the situation changed from unsafety to safety in his mind in a moment. The phenomenon may be attribute with human information-processing rather than that individual characteristic. Therefore, to explore this mechanism may lead to find predictors of accident involvement at the intersection without traffic signals.

As indicated in the example, in considering the influences upon safety judgments, it is not only necessary to clarify the situations which bring about misjudgments but it is even more important to ascertain in detail circumstances resulting in a complete absence of vigilance due to safety factors being indicated immediately prior to that loss. If such situations are frequently generated in traffic streams, their resolution is of the utmost importance in resolving problems of traffic safety.

6. CONCLUSION

The functions of TAAMS for signalized intersections was tested in the field tests, which can detect and display signal states continuously without affecting the control of the normal signal functions. Also, an example of countermeasure is reported, which refer to the road marking for improvement of the signalized intersection.

In addition, an example of decision making of the drivers have been demonstrated through actual example to might been greatly influenced by the vehicular behavior immediately prior to the accidents by TAAMS data and 3DCG images. The images and animation indicate that they are useful tools for studies of the mechanism of accidents.

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REFERENCE

(1) M. Ueyama and M. Koura, "Automatic Recording System and Traffic Accidents at Uncontrolled Intersection by TAAMS". Presented at 15th ESV Conference , Proceeding Vol.2, pp.1476- 1486, 1996.

(2) M.Ueyama, The Study of Traffic Accident mechanism at Intersection by Automatic Receding Systems", Presented at Conference of Road Safety in Europe, Proceeding No.7A, Part 2, pp.95-108, 1996.

(3) K. Rumer, The role of perceptual and cognitive filters in observed behavior. Human Behavior and Traffic Safety, (cite in: L. Evance, Traffic Safety and the Driver, p.92-93,1991).

(4)Side Effects Software Inc., Reference Manual, Vol. I, "PRISMS 6.0", 1995.

Traffic analysis with image processing

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Lund 1997-10-20

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1 Background

One of the major traffic safety analyzing tools used at the Department of Traffic Planning and Engineering is the 'traffic conflict method'. In a simple way we can describe the method as a tool that counts and classifies the near accidents in real traffic. The method has been validated towards accidents with personal injury which means that the result of some days of traffic conflict studies can be used for a prediction of the expected number of accidents with personal injuries for a specific time period, for example a year.

The traffic conflict method, developed at the Department of Traffic Planning and Engineering, is an excellent tool used in a lot of research works at the department during the years. Outside the technique has been used in the daily work by some local authorities, some consulting firms and in some small extent by the Swedish National Road Administration.

The traffic conflict technique is a useful tool in two cases, when you need an instrument to make a quick diagnostic advice and when you want to make a quick study of a proposed traffic safety measure.

The big disadvantage in becoming a more wide spread traffic safety tool is that the technique is quite resource demanding. During the last years we have tried to find out how to use image processing instead of human observers out in traffic in order to improve the conflict studies aiming to develop a tool where the machine should replace the human observer both in the observation phase and how the improved data quality and amount of data could improve the analyzing phase.

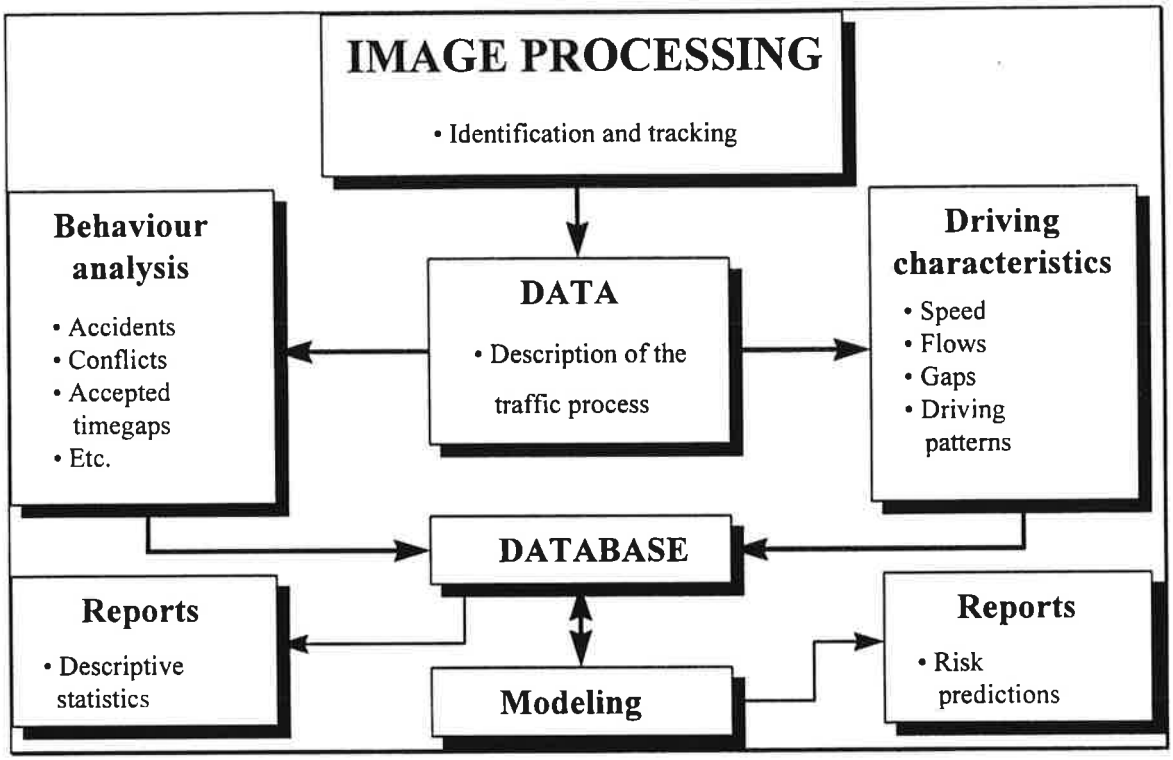
The recent work has looked at the possibilities to use video image analysis to collect the positions of road users during the observation time. The needed level of accuracy in data for conflict studies is so high that this kind of data would also be suitable for a wide range of other traffic related needs. For example a video-based data collecting tool would produce data that can be used for counting both simple and more complex situations with a lot of swerving moves, it can be used for classification of vehicles and for all kinds of speed studies.

A necessary base if you want to study the traffic process is that you have access to a method able to systematic collect knowledge and data in order to judge and explain the safety aspects in traffic. This tool should also be able to follow up consequences of changes in the system. This could be all type of change for example physical measures, changes in the legislation, information and education matters or other things that affect the road users in short or long terms locally or more generally.

We see the image processing system as a base in a broad and multifaceted evaluation-method. Data in the form of speed, traffic volumes, time gaps, interactions and conflicts should be collected and analyzed with new methods that better takes variations in the traffic volumes in to account.

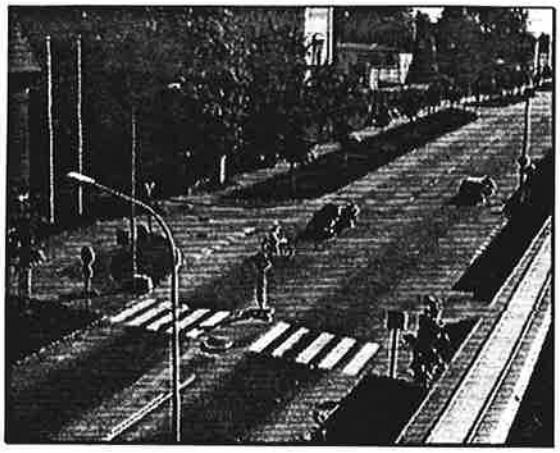
The method should be useful in practice work both for standardized follow ups and for development purposes as well as a tool for pure research work.

A general benefit with a video-based method is the possibility that you are able not only to carry out several traffic safety analyses but you will also be able to demonstrate the result with help of video-based material in pedagogic way for decision makers and for the public audience.

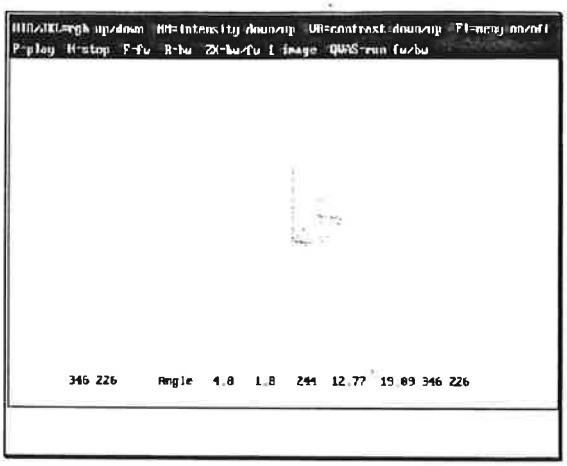


2 Data collection

We have developed a 'semi manual' system where we in the **first stage** use a video recorder with a time code generator and time code reader. The recorder is managed by a PC throw a serial interface. The video screen is displayed on the PC, and with the help of a computer generated footprints the positions are picked from every image of interest..

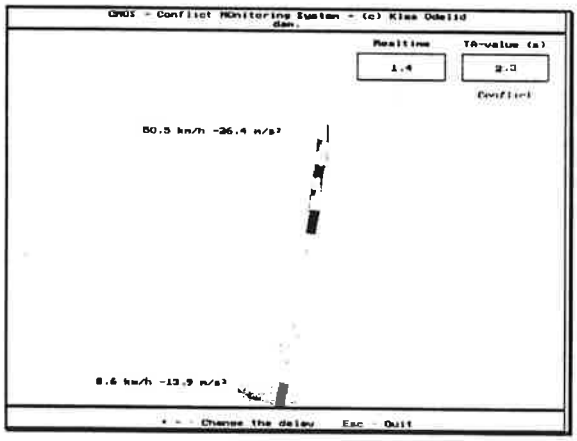


Typical view of a single frame from a conflict situation.



Footprint used when positions are collected in the semi-manual system, the two images are then overloaded in the PC-screen.

In a second phase the data of the positions and the times of the studied road users are analyzed in a similar way that is done with the conflict technique. The system is used in several other research projects at the institution, one locking at accepted time gaps at roundabouts, another studying speed adaptation, and is also dealing with the traffic conflict technique



Example of conflict detection in the second stage.

The next step in developing an automatic system for traffic safety analyses is to replace the first stage's manual data collection with a real-time-based image processing system. We have found some potential candidates for this phase and have carried out some studies with a Swedish system where we are going to compare the old 'semi manual' system with the automatic real-time-based system. The image processing system we have looked closer at is a part in a road tolling system. The first impression is that the accuracy is quite high and absolutely in the correct range for being a candidate for playing a role in an automatic traffic safety analyze system. The first studies were carried out on the Combitech test site and on the European way four. Preliminary result looked very good, and this paper focus of a little deeper look at the accuracy of this system.

3 The need of an image processing system

3.1 Current situation

The primary application for an image processing system in traffic engineering is automatic detection of objects such as cars, lorries, motorbikes, bicyclists and pedestrians. The gathering of data is mainly done manually by observers. The observer estimates parameters such as velocities, positions, distances etc.

3.2 Benefits of an image processing system

An image processing system for object detection (automatic detection of vehicles and pedestrians) would be of much help in for example the conflict technique. Trained observers are humans with humans faults and shortcomings. It can be very straining to observe an intersection a whole day with bad weather fully concentrated. One person cannot simultaneously keep track of a large number of objects and at the same time accurately write down the parameters of each object. Normally there are only two objects involved in a conflict but there are situations when the number of objects are much higher. Position, velocity, direction and distance are parameters which are difficult to estimate even though there is only one object. When the number of involved objects for a given situation rises it's almost impossible to determine the parameters correctly. An image processing system could be out on the field for weeks without getting tired. The amount of gathered data would greatly increase which means that the final analysis probably would be more accurate.

3.3 Fields of application

The primary application is in the conflict technique. But, the image processing system determines only position, dimensions and type of object. How these parameters are used is up to the user. Software could be written to handle other areas of traffic engineering than the conflict technique. Examples of other areas are speed measurement, time lapses in roundabouts, vehicle counting etc.

3.4 Pros and cons with our image processing system

Our semi-manual image processing system makes it possible (after field studies) for us to in detail determine all object parameters. We can detect objects smaller than motorbikes which the Combitech system currently is not capable of. Additionally we can cover a relatively large area. This sounds pretty good but the biggest disadvantage is that the system is very time consuming and requires lots of manual moves. For example, to process (detect positions) 33 seconds of video film (407 logs with a resolution of 0.08 seconds per log) takes about 3 hours. This means that each frame logged takes approximately 27 seconds and a second of film 5-6 minutes.

4 New image processing system - Combitech

4.1 General

There are lots of image processing systems on the market today where image processing methods and field of application varies. Combitech Traffic Systems AB (in this paper referred as Combitech), a company within SAAB Combitech AB resided in Jönköping Sweden, has designed a freeway toll system which includes an image processing system. This image processing system showed to almost meet our requirements. With a couple of modifications the Combitech system would be a potential candidate.

4.2 Pros of the Combitech system

The Combitech image processing system works in real time and is capable of detecting a large number of objects simultaneously. These qualities are the biggest advantage compared to our system. No more image processing is needed when coming home from a field study. However, collected data must be processed in some form of software. This software must be able to handle faults due to detection errors (if there are any). Detected object parameters are position, length, width, height and type of vehicle which is all we need for our applications.

4.3 Cons of the Combitech system currently designed

The Combitech image processing system is designed to be part of a freeway toll system which means that we would get functions that we don't need. Currently the system is blocked so that objects that comes in from the side can't be detected. This blocking is implemented due to the fact that all interesting objects (freeway toll application) are moving either towards the camera or from it. This means that a "side" object probably is some animal which Combitech of course don't want to detect (a deer shouldn't have to pay toll). The detection area are some what small (16×16 m^2). Detectable objects are cars, lorries and motorbikes which leaves the for us so important pedestrians and bicyclists.

4.4 Combitechs adjustments to meet our needs

Combitech has announced that the blocking of objects that comes in from the side is relatively easy to modify (changing the software). This means that our requirement to be able to detect an object wherever it's coming from is satisfied. The detection area can be enlarged by setting up more cameras or changing the camera angle. This leaves the bicyclists/pedestrians problem which apparently is harder to alter but still seems to be a not to big software matter.

5 Comparison between our and Combitechs image processing systems

5.1 General

Naturally, we wanted to examine how well Combitechs image processing system performed in accordance to reality. Unfortunately, reality is impossible to measure exactly (even car speedometers has sources of errors). However, we consider our image processing system to be accurate enough which means that we would be able to compare Combitechs image processing system with ours to determine the performance of the Combitech system.

5.2 Gathering data

The data collection was made at the Combitech test site in Jönköping. During approximately two hours we and Combitech at the same time tested our systems respectively. During this period three cars (of which one was a station wagon) and a lorry was used as test objects. Additionally a pedestrian was simulated by a female holding a box at her back. This, as mentioned before, is required due to the fact that pedestrians normally are too small to be detected by the Combitech system.

5.21 Log format

One second consists of 25 frames and every other frame were logged both by Combitech and us. Consequently, the number of logs second 1, 2, 3, 4, 5 are 12, 13, 12, 13, 12 and so on. These logs were placed by Combitech on a text file on disk for further processing at the Department of Traffic Planning and Engineering in Lund.

5.3 Analysis of data

We have processed a number of situations, 38 to be exact. 21 of these were cars approaching the camera , 8 cars making a turn, 4 lorries approaching the camera and 5 pedestrians walking in various directions. All objects moved with various speeds. Software was written in Pascal with the purpose of presenting objects on screen, calculating velocities and other parameters which were needed for the analysis.

5.31 Method of comparison

The following method was used :

1: Pick a situation and make sure that the time of start and stop for both Combitechs and our logs are identical.
2: Calculate velocities for both Combitechs and our logs.
3: Compare velocity curves and determine the correlation between them.

5.4 Smoothing velocity curves

A major problem is how to handle detection errors (every detection has an error even though it's small). When comparing velocities the velocity curves must as close as possible describe real velocities. To begin with the velocity was calculated as

$$v_i = \frac{\sqrt{\left(X_i - X(i-1)\right)^2 + \left(Y_i - Y(i-1)\right)^2}}{T_i - T(i-1)} = \frac{\text{distance between positions}}{\text{time difference}}$$

where

v_i = velocity log i

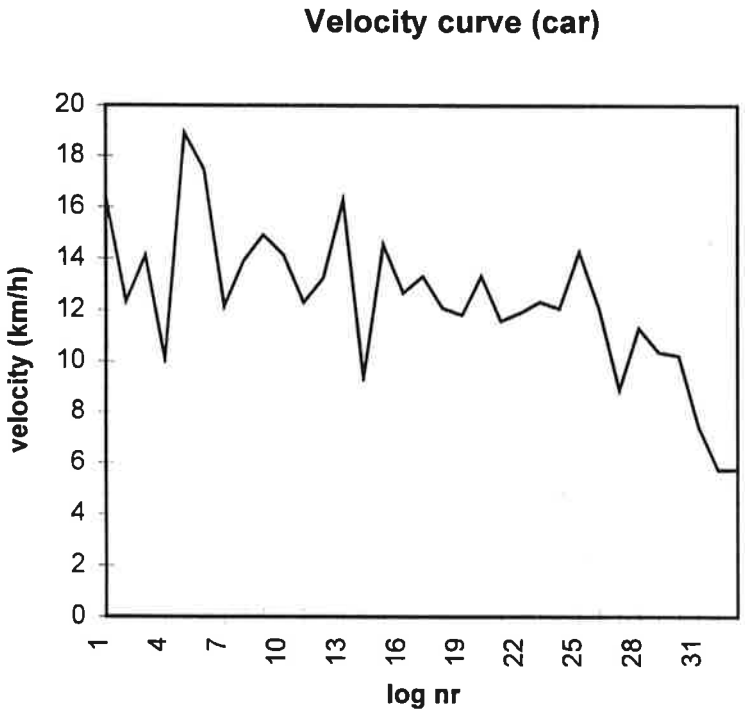
X_i, Y_i = positions log i

X_{i-1}, X_{i-1} = positions log $i - 1$, i.e preceding log

T_i = point of time log i

T_{i-1} = point of time preceding log

This velocity calculation generated a rather jerky curve which not at all described the real velocity curve (example below). This is the case for data from the Combitech site as well as data from our manual video system.



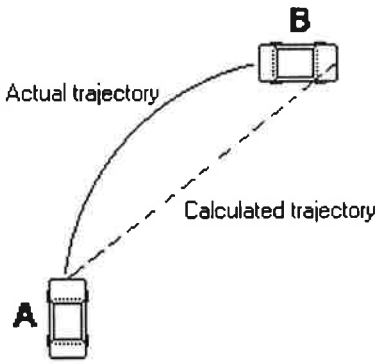
Time lapse between 2 logs are 1/(25/2)= 0.08 seconds.
Since every log is associated with a detection error the velocity could be described as

$$v_i = \frac{\sqrt{\left((X_i + err) - \left(X_{(i-1)} + err\right)\right)^2 + \left((Y_i + err) - \left(Y_{(i-1)} + err\right)\right)^2}}{T_i - T_{(i-1)}} = \frac{\text{distance between positions}}{\text{time difference}}$$

The error varies in some extent, that is, the further away from the camera the object is detected the greater detection error. This fact is at this point of secondary interest. More interesting is that the longer the distance is between logged positions the less the velocity calculation is influenced by the detection error. The velocity calculation gets to be more accurate the faster an object is moving. If an objects velocity is low the velocity curve is going to be very jerky if the time lapse = 0.08 seconds is used. This problem can to some extent be solved by increasing the time lapse between logs. If the time lapse is increased an other problem will arise which is shown using a couple of examples.

Example 1

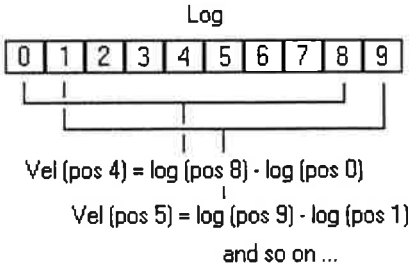
Suppose a car is making a curve between A and B with constant velocity. This maneuver takes 5 seconds. If the time interval was increased to 5 seconds between logs the velocity calculation would be faulty because the calculation would be based on a straight line between A and B without any consideration to the curve.



Example 2

Suppose a car is driving with various speed in a straight line between A and B. This takes 5 seconds and the time interval is increased to 5 seconds. The velocity calculation would give the mean velocity between A and B which means that the variation in speed wouldn't be detected.

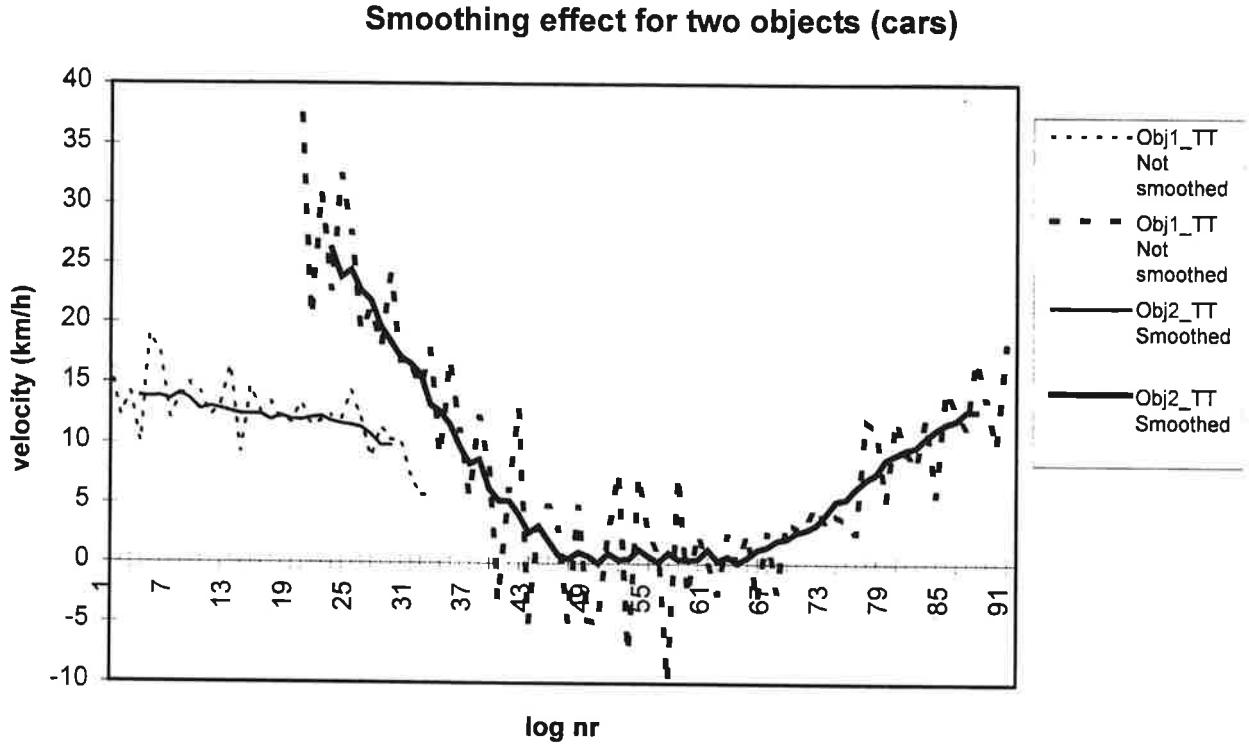
Consequently, there is a limit for how long the time interval can be. This limit should be set so that the detection error is taken care of without losing the variation in velocity. We have tested numerous methods of smoothing the velocity where the following method so far is shown to be the best.



Thus, the velocity in for example position 4 is calculated as

$$v_4 = \frac{\sqrt{(X_8 - X_0)^2 + (Y_8 - Y_0)^2}}{T_8 - T_0}$$

The time lapse = 8×0.08 = 0.64 s.



5.5 Correlation's between Combitechs and our velocities

A total number of 38 situations (objects) have been studied with this smoothing method. Each situation has generated 2 velocity curves (Combitechs and ours). These two curves have been compared by calculating the coefficient of correlation between them.

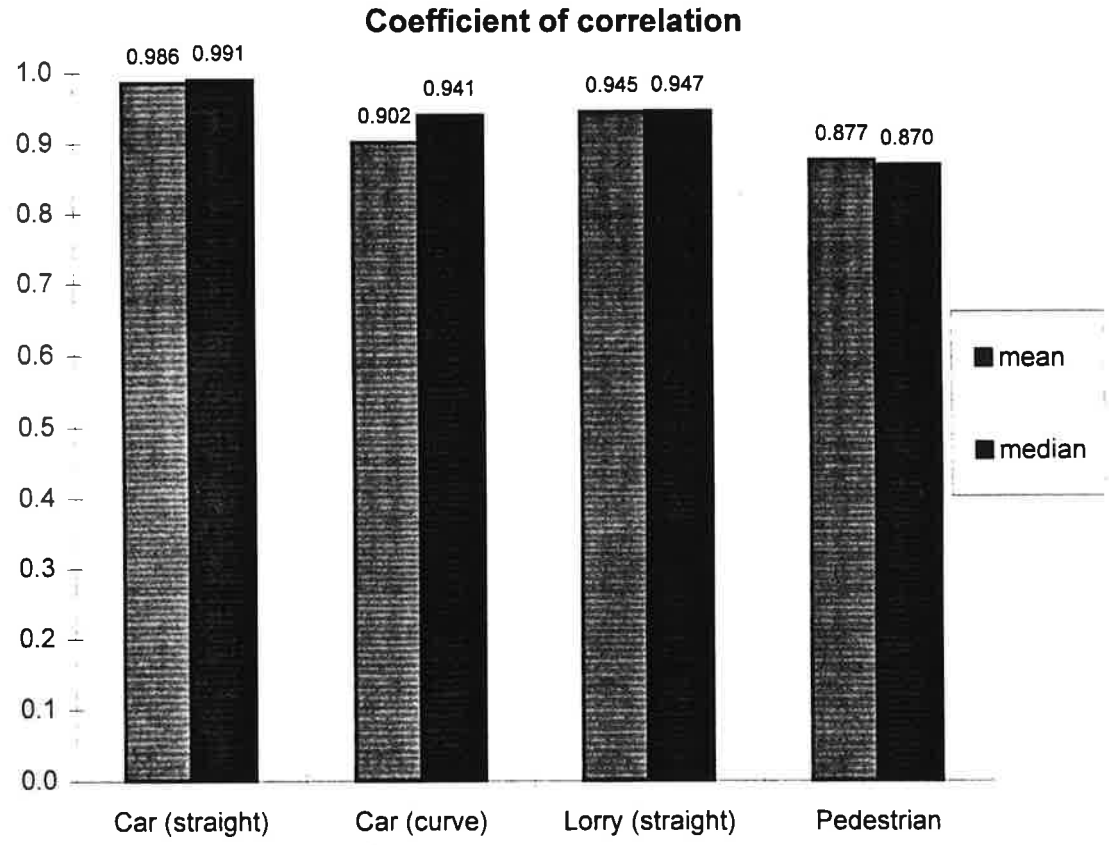
The coefficient of correlation measures the relationship between two sets of data (velocities in this case) adjusted to a scale which makes them independent of unit of measurement.

Coefficient of correlation =

-1 means that low values in data set 1 corresponds to high values in data set 2.
0 means that no correlation exists between the data sets.
1 means that high values in data set 1 corresponds to high values in data set 2 (also means that the two data sets are identical).

The coefficient of correlation for all situations are declared in the figure below.

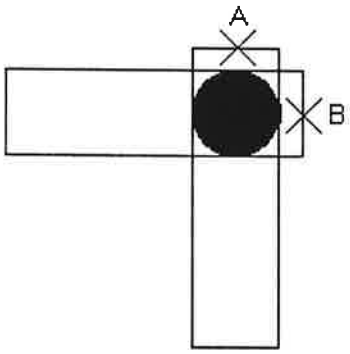

Coefficient of correlation for all situations
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Car (straight)
Car (curve)
Pedestrian
Lorry (straight)


Coefficient of correlation
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.986
0.991
0.902
0.941
0.945
0.947
0.877
0.870
mean
median
Car (straight)
Car (curve)
Lorry (straight)
Pedestrian

6 Results

- Objects moving straight forward (even with various speeds) towards the camera have very good accordance to our system.
- Objects making a curve are detected relatively accurate.
- Lorries are detected with some what lower accuracy than cars. A theory of this fact is that lorries are bigger than cars and that the classification therefore will take longer time. This causes the detection to be more "jumpy" (before classification). Classification means that an object are recognized as a car, motorbike or lorry.
- Pedestrians are detected with relatively good accuracy (lowest accuracy of the objects).

The reason why pedestrians have the lowest accuracy probably is due to the fact that pedestrians are classified as motorbikes if they at all are classified. The classification as a motorbike means that the Combitech system assigns the pedestrian the same size (length, width) as a motorbike. This will have consequences if, for example, the pedestrian stands still and turns his/her body. We tried to hold the box so that the front would align in a vertical line with the body's center of gravity. The front unfortunately often landed outside this gravity line which means that the Combitech system detected a body turn like a movement between A and B (se figure below). The filled circle represents the pedestrian, the rectangle the box and the cross the front of the box.



A comment must be made concerning the car (curve) block (the leftmost bar) in the "Coefficient of correlation for all situations" bar graph. The coefficient of correlation is rather low (0.6). In this case the Combitech system lost accurate detection of the car at one point and instead detected the shadow of the car. This could be denoted as a serious problem but it really isn't. Reason number one is that it happens occasionally when it's really shiny weather (this is rare in Sweden). Reason number two is that it can be corrected by good software programming. In this case one would take advance of the fact that a car cannot suddenly jump 90 degrees half a meter to the left (or right). Actually, it's a good example of minor problems that software can take care of.

In total, we are very happy with the performance of the Combitech image processing system. In a near future we would like to see this system or a similar system with the same accuracy as an integrated part in our applications.

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Psychological Aspects of Accidents in Area of Road - Railway Grade Crossings

1. Introduction

From history, we remembered the first period of motorization. The famous English law - *The locomotion act* for many year stopped development of that branch. Cars could only following the man with red flag, which was warnig pedestrians against automobile.In that time, the railway was been victorious after first falls and time of unpopularity. In that first historical period , railways used of traditonal human pathes as valleys of a rivers, sea sides etc.In many cases, tracks crossing old roads but very low frequency of trains was not the special disturbance for people.Therefore railway received the privilege of priority very easy, as the meant of mass transportation. It was a genesis of *rail - road grade crossings.*
Now, we have many such crossings and many problems in every countries.

2.Some Facts and Statistics

In all Europians countries , we have many thousands of poins of probale collisions *train - vehicle.*
Table No 1 shows number of such crossings in Europian Railways Organizations and average density (crossings/ km of railway line). There are various . But from our point of vies, more interesting is a frequency of accidents on rail - road grade crossings in Europian Countries. These data I prezent in the next table No 2. You can see, that I can be proud because in 1990 ,Poland occupied the fourth position in Europe, and had been better than eight position of Deutschland . Unfortunately, since 1990 , situation quickly fall down . We have two probably reasons of that changes:

1. The frequency of trains on Polish State Railways discreased as result of another economic strategy.
2. It leads to limitation of number of R - R crossing, especially crossings watched by staff of railway.

One of results of such situation was increasing of accidents number from 131 in year to about 300 per year (near 2.5 times accidents more). In that time, BundesBahn designed for improvement of traffic safety level on rail - road crossings amount 0.75 mld DM in each year. High intensivity of these efforts significantly influences the number of accidents between trains and vehicles. It was reduced from 445 to 228 at last about 50%.

It is true, that accidents on rail-road crossings there are only small part of general number dangerous situations in traffic (in Poland - 0.53% of all traffic accidents , 1.71% of fatal accidentsw and 0.23% of all accidents. But we m ust point, that from psychological point of view, crash *train - vehicle* is horrible and tied with very tragic consequences. They are especially outrageous for public opinion .In Polish law regulation . the accident on area of rail-road grade crossing belongs to the cathegory of railways accidents (exactly *train accident)* but not registered as normal traffic accidents

We can not forget about *near \accident* problem ,too. In Poland ,each year 320 bareer are broken, on the rail-road crossings. In practice , such situation had been happened everyday. From one hand it shows the real shape of that phenomenon, but from the other hand it could be a picture of lack of discipline of polish drivers.

3.Formal Regulation of Rail - Road Crossings

The Management of Polish State Railway divides Rail - Road Grade Crossing into four basic cathegories. There are following types:

- **the cathegory *A.*** Crossings , protected by full bareers and cotrolled by railway staff.[3360 crossings - 26 accidents in 1995 , *accidental coefficient* - 0.71).
- **the cathegory *B.*** Crossings, protected by half-bareer, eventually supported by red blinking lamps. Moving bareers and switching on lamps realize by automatic system, initiated by coming train.[257 crossings - 10 accidents, *accidental coefficient - 3.89)*
- **the cathegory *C.*** Crossing with only blinking lamp, switch on by coming train from time distance 60-80 sek. [1539 crossings , *accidental coefficient - 5.59]*
- **the cathegory *D.*** Crossing with only typical road and rail signs and nothing more.[11860 crossings]
  176 accidents, *accidental coefficient - 1.48]*

From the psychological points of view, most interesting for us there were two last cathegory of Rail- Road grade crossings. On the two first, drivers had to stop theirs vehicle, because the way is closed by bareers and , practically only breaking of its or errors of railways' staff leads to an accident. In the last cathegories, the way is everytime open, but at last, a driver deceides when and where hist vehicle is be stopped. It is interesting too, the accidental coefficient for cathegory C is relatively higher that for cathegorie C, where the driver receives an information that train is just coming to crossing. In crossings, which belongs to cathegory D, such information is not available, and driver had to be careful. Therefore the accidendal coefficient for that cathegory is relatively low, but in rough accidents statistic, most of them took place in that cathegory of rail-road grade crossings. Traffic safety is tied strongly with decision making proceedure. Therefore our investigation concentrated on these two last cathegories .

4.Methods

We practically used four main methods in our research of psychological problems on R-R crossings:

1. **Analysis of statistical data**, which delivered to us by General Management of Polish State Railway.It contained basic information about all R-R accidents in 1995 year with

the time, day of year, place of collisions , its consequences, list of victims and damages and eventually name of causer.

2. **Questionnaire for drivers** about theirs experiences tied R-R crossings. That questionnaire specially prepared for our research and printed in most popular Polish journal for lovers of motorization - „MOTOR" (80.000 of prints). The questions directed on evaluation technical state of R-R crossings own experiences of road users, their behaviour and observations of other drivers.
3. **Observations of drivers' behaviour in R-R crossings.** We made it with the help of video camera and cordless microphone , which give possibility to record additional information and the comments of the observers. We observed activity many drivers on R-R crossings cathegory C and D in such forms as: speed, stopping vehicles, method of control of space before and in area of the crossing etc.
4. **Deep analysis of accidents in R-R crossings on the base of railway and police reports and other sources.** For that goals we select two fatal accidents ,which happened in district of Cracow.

5. Results

5.1. Main Results of Analysis of Statistics Data

1. Most of accidents in R-R crossings were caused by drivers. Only 12 accidents caused by railway workers (only in cathegory A). We could not find some relations between accidents and such determinants as: hour, day of week , weather conditions and season of year. Probability of accident is tied with the frequency of trains and frequency of passing vehicles. The random factor plays important role in generating of accidental situation, but most of them had the character only *near accidents.* We had to accept the Hepburn theory, that accident happened only, when all accidental factors appeared in exactly this some time.
2. We have in Poland 320 accidents in year, in average 1 accident daily. But we had each year about 300 cases of breaking bareers on the R-R crossings A and B cathegories.. It is evidence of many near-accidents, which happened when a driver avoided the crash his vehicle with a train.
3. The role of alcohol as determinant of accidents in R-R crossings grows and grows.Very often we found in statistics of accidents, the information that vehicle no braked the front of the train but crashed the flank of engine or coaches or vans . We have 2 accidents, when te motorcyclists had collision with train ,which was waiting for green signal just in area of R-R crossing . It is clear that drivers seriously ignored the traffic regulations and self-discipline

5.2. Results of Questionnaire for Road Users

Our questionnaire was printed in the Polish journal „MOTOR" . We got forms, filled by 226 readers from all parts of country. There were in bigger part unprofessional drivers (79%) . They had a possibility to evaluate the quality of surface and quality of road signs in area of R-R crossings. Their opinion shows the figure No 1.
. You can see, that most of our respondents had very bad opinion about the surface in area rail and road crossings. Many drivers said with sarkasm, ,that bad surfase forced them to reduce their speed and this fact is a factor , which guaranted the traffic safety in this area. We have also the answers , that people responsible in Poland for that catastrophic state of surface, ought be trained in the Bundesrepublic
.Our drivers more satisfied for the quality of road sign in area of a crossings. It show fig. No 2. We could not relation between experience of drivers and their ignorance of traffic safety principles. Sometimes in wery well known crossings, they pay attention for timetable of trains. It is very significant, that more about 30% of respondents saw situation ,when a car had been closed on a tracks among a bareers. It supported our hypthesis about great number of near-accidents on the crossings.

5.3 Results of an Observation of Drivers' Behaviour in R-R Crossing Area

.In first part of our analysis we said , that the drivers had tendency for demonstration of dangerous form of behaviour. The General Management of Polish State Railways prezented similar opinion. But our observation supported that opinion only in part. We noticed only 1 situation, when the driver completely ignored red blinking signal .Generally , we recorded four types of drivers' behaviour ,when drivers were crossing the tracks

- *stop ,before tracs;*
- *observation of area of crossing by a driver;*
- *driving in the area R-R crossing , without stopping vehicle;*
- *driving in the area R-R crossing without observation and without reduction of speed.*

But the relation between these types of drivers' behaviour was different for cathegories C and D.It show in fig. No 3 and fig No 4. It is clear, that in R-R crossings cathegory B, the percentage of more dangerous forms of drivers' behaviour had been minimal . But in area of R-R crossings of cathegory D, where probability of collision is greater, drivers demonstrate bigger percentage of evidently dangerous of form of behaviour. What is reasons of such differences? We could give two probable answers.

1. The frequency of trains in R-R crossings both cathegories could be different too, and experienced drivers know the probality , that the train comes , is smaller on crossings cat. C than cath. B. But that explanation is not satisfied for us.
2. According the hypothesis of Lars Aberg , drivers had tendency for avoiding troubles by ignorance of difficult problems on R-R crossings. Undobtely, the situation in the R-R crossings cathegory D is unclear for driver, and therefore, when he has not a full control of s the situation, (for ex. in spite of limitted visibility etc.), he simply ignored the risk of crashing and driving his vehicle quickly and without any observation. Our results supported that hypothesis. It suggest , that efforts of Management of Polish State Railway ought to more intensively changes cathegories of R-R crossings from D to C. It needs reconstruction of these crossings.

5.3. Results of Deep Analysis of Accidents in R-R crossings on the Base of Railway and Police Reports and other Sources

For this goal ,we select two fatal accidents, which happened in 1996 on the South of Poland.

++ In the first accident, two young ladies came into rails with minimal speed of theirs car (about 10 km/h) .It was happened in R-R crossing cathegory D (without blinking lamps). The girl , who was driving, notice the engine ,which was coming in the last moment , she rapidly accelerate her car, and motor stopped in this moment. The visibility of arrounding that crossing, had been very limitted , by bushes, and driver of engine could not to see a crossing car ,earlier. Heavy engine crashed small car and both girls were be killed. In expert's opinion - they had only 2 second for starting motor of their car again or escaping out from the car. From the psychological point of view, we had here typical lack of driver's attention. Our investigation explained of the reason of it. The girl was be a owner and driver of that car, came with the visit to her fiance, who worked as the salesman in a shop near the crossing.In witnesses opinion , she moved her car and driving without control of area in front of her car, which running forward with minimal speed. She did not noticed the engine on the rails. Two photos show the picture of R-R crossing and the point of view from the cabine of engine driver.On first of them ,you can see group of investigators

+ Similar situation we investigated on the R-R crossings cathegory C (with automatic signalization) nearby Zakopane. The fatal accident was caused by young montainer, who lived nearby the crossing. He was the driver of small fiat 126. On the fatal morning ,he ignored red blinking signal and his car did not stopped before a tracks. The consequences of crash were be terrible: killed driver and smashed car. Official report of the investigate comission show as the main reason of the accidents the lack of driver's discipline. But people said that young driver had been hollow drunk and he listened a pop music by earphones of his walkman . These facts were not a true.The victim's family reported, that in the fatal day , the driver waked up very late and he went to his job in hurry. He paid attention at the red signal (which switched on 80 sec before coming the train) but he did not know how long the lamps blinked and deceided to cross the tracks. It was characteristic , that young driver had no any driving licences, but after several attemps, at last he passed through the exam. His first driving licences he wanted to take from the office just in the next day.

These examples show that in most of accidents is very diffcult to precise of the role of human factor , especially quality of processes of decision making. Sometimes, the true is never be discovered

6. Conclusions

1. The system of clasiffication of R-R grade crossings must be changed. New rules of classification had to calculate the frequency of trains and frequency of vehicles but frequency of accidents, which happen in the R-R crossing, too.
2. The psychological aspects of accidents in R-R crossings ought to discuss with a drivers and candidates for driving licences, in the programs of the basic and improvement training.

3. The processes of making decisions by drivers in R-R crossings would be more simplied. It could be realize by changing their structure from cathegory D to C or B, when the driver got clear information that the train is coming or not coming.
4. The surface in R-R crossings had to improve.

THE EFFECT OF DRIVING SPEED ON SUBJECTIVE SAFETY EVALUATION

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Abstract

This research objective was to investigate the effect of the 3D/4D dynamic road environment on drivers' perception of road characteristics, in particular to evaluate the effect of driving speed on the perception of road parameters and road characteristics, in order to search for relationships between driving speed and the perception of road environment and subjectively perceived road safety. The laboratory experiment has been conducted to get a better insight into the speed effect on the perception of alternative road design. The results demonstrate that dynamic perception of road infrastructure has a very significant effect on the subjective safety assessment and on the choice of driving speed.

Introduction

The question *„What has to be considered in establishing modern highway geometric design guidelines ?"* is very tempting and exciting. While several important goals for highway geometric design (like capacity, function, economy, environmental protection) are regarded today in more or less satisfying way, great deficiencies still exist when analysing and evaluating the important goal ***safety***. Highway geometric design guidelines should guarantee the design and construction of safe roads. However, that dose not seem to be true. It is estimated, that about 50 % or more of the fatalities on the European roads can be attributed to two-lane roads outside of built areas, and at least half of these serious accidents occur on curved road sections.

The safe and efficient movement of traffic is greatly influenced by the geometric features of the highway. A review of accident spot maps shows that accidents tend to cluster on curves, particularly on very sharp curves (Lamm et al, 1994). Even though the design engineers possesses detailed information from standard values on driving through a curve, accident frequency often appear to not coincide with the actual driving behaviour.

How to design safer roads still remains the fundamental question that civil engineers, practitioners and researchers specialising in the field road design are trying to investigate. A number of unsolved problems exist in the field of road design, human behaviour and road safety. It is recommended (Wegman, 1996) that the production of best practice guidelines, incorporating all available knowledge with a sufficiently sound scientific basis is drawn up and periodically updated if necessary. It is advised that international research is carried out concerning road design, human behaviour and road safety, in which efforts must be done to develop a co-operative research community within Europe.
Numerous individual research are being carried out in most of European countries, discussing geometric road design problems related to driver's behaviour and perception. Numerous research methods are employed in these studies, presenting a wide range of traditional and modern approaches. One of the approach, presented in the paper, is based on the 3D and 4D visualisation of alternative road designs and road view perception studies.

Experimental design

The experimental research objective was to investigate the effect of dynamic road environment on the driver's perception of road characteristics, in particular: to evaluate the effect of driving speed on the perception of road parameters and road characteristics, to search for relationships between driving speed and the perception of road environment and subjectively perceived road safety and to search for relationships between subjective and objective information received from the observed, dynamic road view.
A multifactorial laboratory experiment was designed to test how the change of driving speed (decreasing 20% below or increasing 20% over the speed limit) affects the proper perception of the road view observed.

Method

Independent variables constructed an experimental driving speed (each experimental road section was recorded three times, namely while driven with the design speed, the designed speed increased at 20% and the designed speed limited at 20%), geometric road parameters (basic road curves design parameters as curve radius and deflection angle) and road environment characteristics.
To test driver's perception of road environment, subjective rating scales were used as the measures of dependent variables. The experimental dependent variables were the subjectively perceived road parameters and road view characteristics, such as road safety, road legibility, fluency, aesthetics, road environment and landscape attractiveness and choice of speed.

Rating scale

The same seven point graphical rating scale was used for six road view characteristics assessments, as in the previous authors studies [Żakowska (1994),(1995),(1996)]. The theory underlying the choice of this scales has well been documented by Heino et al.(1990). Figure 1 represents the scales incorporated in this research.

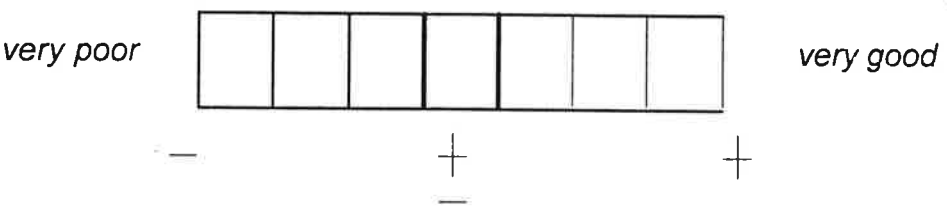


Figure 1. Rating scale used in the experiment

Stimuli

Two-lane rural highways in southern Poland were chosen as an experimental polygon. All stimuli were selected from the same category roads (the third technical class roads, designed at 80 km/h speed, with 70 km/h speed limit), that represents the majority of roads in the region. They varied in three groups of parameters, as shown in Table 1.

Table 1. Design and environmental characteristics of the experimental road sections

SECT. NR	DESIGN SPEED [km/h]	DRIVING SPEED	CURVE PARAMETERS Rh [m]	*fi* [deg]	direction	ROAD ENVIRONMENT greenery	traffic	pedestrians
1	80	90	500	20	R	-	+	+
2	80	90	500	32	R	+	-	+
3	80	90	300	56	L	+	-	-
4	80	70	1000	20	R	-	-	+
5	80	70	500	32	L	+	-	-
6	80	70	300	56	L	+	-	+
7	80	70	500	20	L	-	+	-
8	80	70	500	20	R	+	+	-
9	80	70	500	32	R	-	+	-
10	80	70	1000	20	L	-	-	+
11	80	50	1000	20	R	-	-	+
12	80	50	500	32	R	+	+	-
13	80	50	300	56	L	+	-	+
14	80	50	500	20	R	+	+	-
15	80	50	500	20	L	-	+	-
16	80	50	500	32	L	+	+	-

For each segment a video of the dynamic view was recorded from the driver's point of view, whilst driving with the speed presented in Table 1, respectively. Each stimulus was approximately 60 second long and covered the uniform characteristics for the road segment represented. To eliminate the influence of non manipulated external factors, all sites were filmed in summer driving conditions, good light and weather and none or limited traffic on the road.

Subjects

21 subjects took part in the experiment. They were all licensed drivers of different driving experience-from very experienced, (over 200 thousands km driven and in possession of a driving licence for over 10 years), through experienced drivers (50-100 thousand km driven), to inexperienced, novice drivers 1-3 thousands km driven and possessing a driving licence for no more than 2 years). Subjects were not paid for their participation in the experiment.

Procedure

Unlike in former experiments [Żakowska (1994), (1995)] the motion road views were presented with use of a video projector on a large screen, (2m x 3m) in a laboratory environment, giving the subjects a closer simulation of the real driving environment. Subjects were tested in groups of 4 - 6. The laboratory conditions were the same as during the former *road category experiment* described in Żakowska (1996). A pre-recorded tape of experimental instructions and a practice film were presented as a training at the start of the session. then the sequences of 16 film-clips were presented, with 30 seconds of blank film between each clip, when subjects made their assessments on the response booklet provided beforehand. The experiment consisted of five sessions.

Results

Individual ratings were preorganised and selected with the help of the EXCEL program, and statistically analysed using STATGRAFICS end EXCEL programs. For each dependant variable a separate analysis was performed, based on descriptive methods and one-way ANOVA. The most significant results are presented below.

Speed effect on subjective road parameters and characteristics perception

The effect of speed manipulation on subjective assessment of six characteristics, namely: (1) the subjective estimate of the chosen speed, (2) road safety, (3) attractiveness of road environment, (4) road aesthetics, (5) road legibility and (6) road fluency, are presented in Figure 3.

The comparison of subjective mean assessments of the above characteristics (Fig.3) have revealed that:

- road safety, legibility (readability), and fluency assessments increase with the lover driving speed and these characteristics are well correlated,
- road aesthetics and road environment attractiveness assessments decrease only with an increase of driving speed above speed limit, lover driving speeds than the design speed do not effect the driver's perception of road attractiveness and aesthetics,

- speed choice mean assessments tend to be overestimated, increasing with the decrease of actual driving speed.

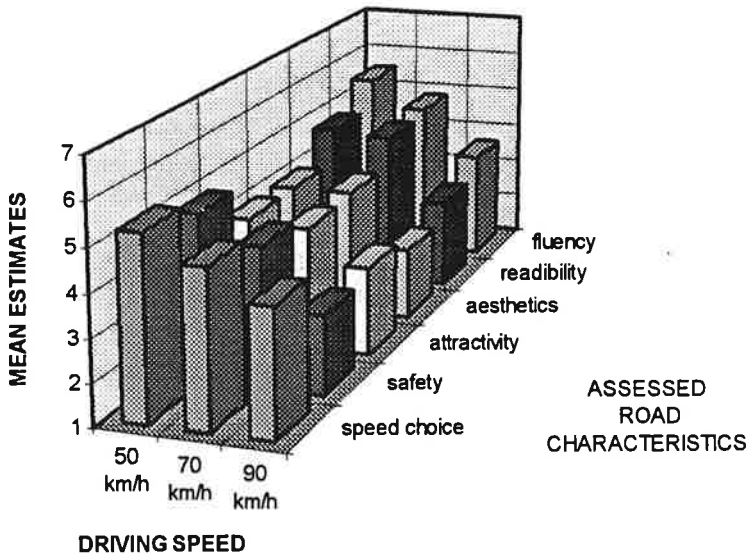


Figure 3. The effect of driving speed on subjective estimates of road characteristics.

Interestingly, there is stronger relationship (fig.3) between speed choice and the perceived road fluency, than between speed choice and the subjectively perceived safety. The more fluent drivers perceive the road the higher speed they would choose while driving at speed limit as well as slower or faster than speed limit.

Road design parameters effect

The effect of road curve design parameters on subjective safety perception were studied during former experiments conducted on the static stimuli by the author and well documented (Zakowska 1995). Three different experimental speeds were incorporated into the research now in order to investigate the composed effect of road geometric parameters and driving speed on subjective choice of speed (Figure 4), subjectively perceived safety (Figure 5) and subjective assessment of road curvature and road curve deflection angle (Figure 6 & 7).

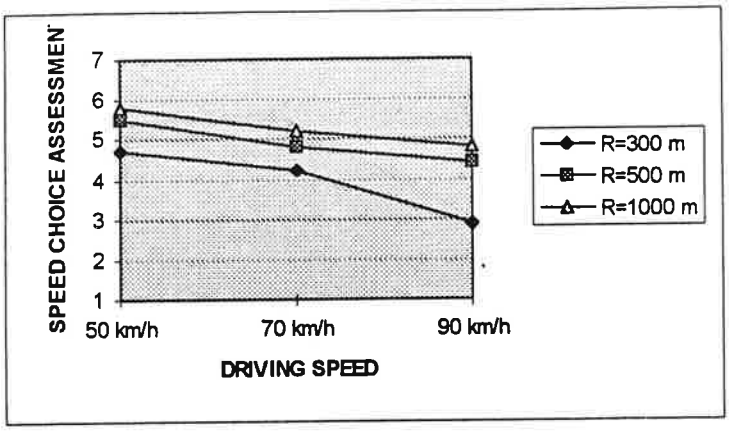


Figure 4. The effect of road curve design parameters on the subjective choice of speed assessment, at different driving speeds.

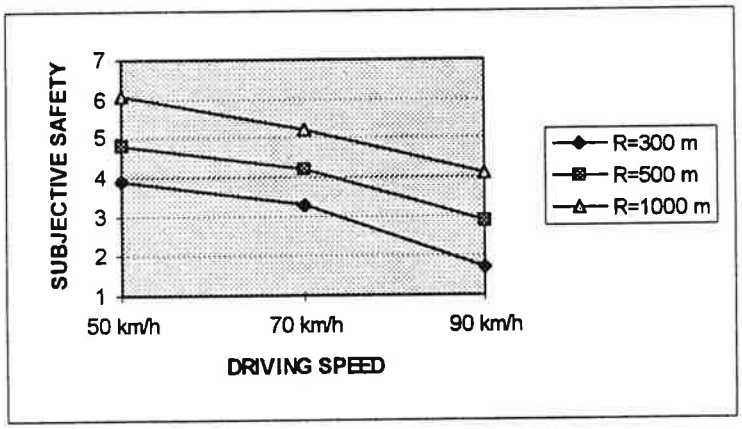


Figure 5. The effect of road curve design parameters on the subjective safety assessment, at different driving speeds.

It has been shown (Fig.5), that subjective safety increases with decrease of driving speed for each curve radius tested in the experiment. Moreover, the results demonstrate that subjective safety assessment increases with an increase of the road curve radius, while driven with the same speed along the road of variable geometry. This results supports the former findings (Zakowska,1995 and Theeuwes, 1995), that road behaviour is related to road design.

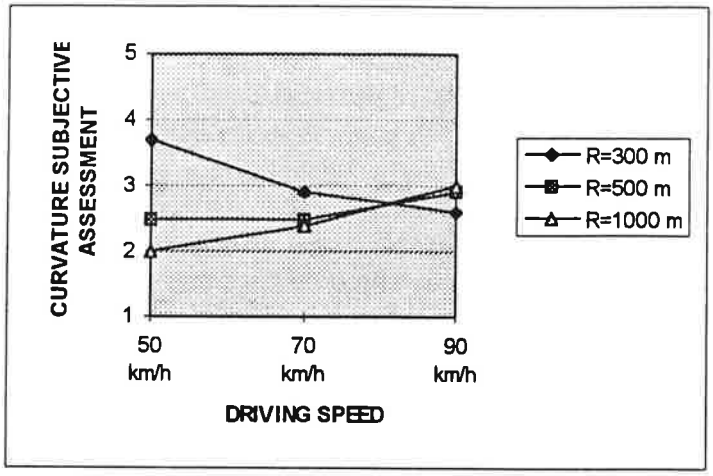


Figure 6. The relationship between objective and subjective curvature of the road driven at different speeds.

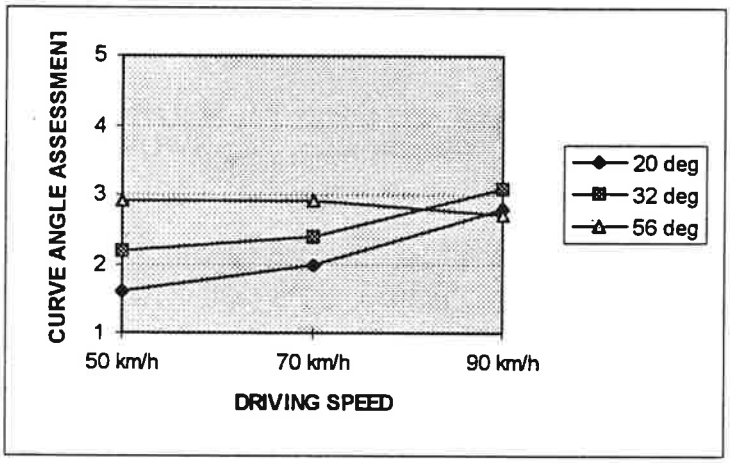


Figure 7. The relationship between objective and subjective curve deflection angle estimated at different speeds.

Conclusions

Earlier road perception studies in this series, conducted by the author, (Zakowska 1994, 1995, 1996), were directed at the lower road categories driven at the designed speed, while here, special attention was paid to the III-rd class roads (with 80 km/h design speed), but driven at three experimental speeds. This study demonstrates that dynamic perception of road infrastructure has a very significant effect on the subjective safety assessment and on the choice of driving speed. Such a road view elements as side lines painted, gentle curves and good preview, or high quality of the pavement, result in higher assessment of road

aesthetics. Especially for higher driving speeds, choice of speed is well correlated with the proper perception of the road characteristics. The higher speed of driving, though, the more attention should be put on the road fluency and road aesthetics, realised in a total care for the proper road view perception. This study supports the general finding of Tenking and Horst (1991) and Theeuwes (1994), that road behaviour is related to road design. This study furthermore demonstrated, that driving speed is strongly related to the way road users perceive road environment. To achieve safe traffic behaviour, drivers expectations, that the road environment elicits, must be in line with how road users should behave on these road. If this is realised, than one can speak of a genuine self-explaining road environment.

References:

HEINO A., MOLEN, van der, H.H. & WILDE, G.J. (1990). Risk-Homeostatic Process in Car Following Behaviour, Report VK 90-22, VSC Traffic Research Centre, RUG Haren.

LAMM R., PSARIANOS B. & GUENTHER A.K. (1994). Interrelationships between Three Safety Criteria, Modern Highway Geometric Design, as well as High Risc Target Locations and Groups. Proceedings of The Third International Conference on Safety and the Environment in the 21th Century, November 1994, Tel-Aviv, Israel, pp.439 - 449.

RUYTERS H.G.J.C.M., SLOP M. & WEGMAN F.C.M. (1994). Safety Effects of Road Design Standards, Report R-94-7, Leidschendam, NL: SWOV Institute for Road Safety Research.

TENKING, E. and HORST, A.R.A. van der (1991). Effects of road width and curve characteristics on driving speed. TNO Institute fir Perception Report No. IZF-C-26.

THEEUWES J. (1994). Self-Explaining Roads: an Exploratory Study, Report TNO-TM 1994 B-18, Soeterberg, NL: Human Factors Research.

THEEUWES J. & DIKS G. (1995). Subjective Road Categorisation and Speed Choice, Report TNO-TM 1995, B-16, Soesterberg.

WEGMAN, F. (1996). Road Design, Human Behaviour and Road Accidents: towards a 'learning design community'. International Conference "Road Safety in Europe" Proceedings, Birmingham, SWOV Report D-96-6.

ŻAKOWSKA L. (1994). Road Curve Evaluation on the Basis of Road View Perception Studies, Doctoral Thesis (unpublished), Cracow University of Technology, Civil Engineering Department, Poland.

ŻAKOWSKA L. (1995). The Effect of Environmental and Design Parameters on Subjective Road Safety - a Case Study in Poland, *Safety Science Journal* No.19, Elsevier Science

ŻAKOWSKA L. (1996). Dynamic Road View Research for Road Safety and Aesthetics Evaluation. The 7th ICECGDG Proceedings., Kraków, Fotobit Poland, Vol.I, 276-279.

4. ACCIDENT STUDIES

Chairperson: Hans Mohlin

• **Effects of speed limits decrease in 1996 on incidence and severity of injuries sustained in traffic accidents in the city of Zagreb.** MIRIC Marica, PROMETI Ltd. KEJLA Zvonko, BULJAT Gojko, University Clinic for Traumatology in Zagreb, Croatia

• **Raising the Speed Limit on Motorways - Is It Always a Bad Idea?** HOCHERMAN Irit, Transportation Research Institute, Israel

• **Characteristics of some accident circumstances on road blackspot sections.** NOWAKOWSKA Marzena, TRACZ Marian, Laboratory of Computer Science, Cracow Univ of Technology, Poland

• **A Study of Accident Mechanisms on an Urban Motorway.** GITELMAN Victoria, HAKKERT Shalom, TECHNION, Israel

• **Headways, collisions and traffic: some results on French motorways and towards new questions.** BIECHELER Marie-Berthe, PEYTAVIN Jean-Francois, ARON Maurice, INRETS, France. HAKKERT Shalom, TECHNION, Israel

• **The determination of the total number of hospitalized traffic victims by comparison of police and hospital reports**. POLAK Peter, OPPE Siem, SWOV, the Netherlands

• **Simulation of car-pedestrian impacts. A new human-body mathematical model** LÖVSUND Per, Dept of Injury Prevention, Gothenburg, Sweden

• **Relative Collision Safety in Cars.** VADEBY Anna, Linköping University, Sweden

EFFECTS OF SPEED LIMITS DECREASE IN 1996 ON INCIDENCE AND SEVERITY OF INJURIES SUSTAINED IN TRAFFIC ACCIDENTS IN THE CITY OF ZAGREB

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Prometis Ltd, Zagreb, Croatia
Kejla Zvonko, Buljat Gojko
University Clinic for Traumatology, Zagreb, Croatia

1. INTRODUCTION

Injuries sustained in traffic accidents are virtualy accurately explained by plain physical laws, where delivered and absorbed energies are well determined, therefore predicting the severity of injury.[4,5,6,17] By those simple laws, the energy should be defined by the moving masses and their relative velocity, as well as by the time and the path of deceleration. Since the velocity presents itself as a most significant factor in kinetic energy equation, the obvious means to reduce the possible injury in traffic accident could be the reduction of traffic speed, reducing the energy delivered in an automobile crush.[3,7,12,14] Other means were determined to the absorption of accepted energy, and included strengthening of construction of the vehicle and other instruments, as were different types of seat belts and airbags introduced to protect the occupants in the vehicle.[1,2,8,10] Refinements of traffic areas with strict and physical dividing of walkway from the motorway are intended for the protection of pedestrians. Education of drivers and pedestrians should be the most significant part of accident prevention, but unfortunately, it was well established that the legislative and adomistration meassures, in conjunction with possibility of significant castigation lead to coccmprehensibly better results[13].

Although all of these tactics were tested and their efficacy had been well documented, the reduction of traffic speed was always the cheapest and most easily applicable means to reduce the severity of sustained injuries and therefore diminish the morbidity and mortality resulting from traffic trauma.

It was our intention to check the efficacy of new traffic speed limitation law, brought by Croatian Parliament in may 1996. on the incidence and severity of injuries sustained in traffic accidents in Zagreb metropolitan area and to challenge it's long term results.

2. MATERIAL AND METHOD

Statistical data about the incidence of traffic injuries which took place in Zagreb metropolitan area, were collected from Traffic Department of Municipal Police Zagreb, and correlated a for the severity of sustained injuries with data from University Clinic for Traumatology Zagreb, which serves as a primary trauma center for whole Zagreb metropolitan area. We covered 1996. year trying to find any difference in the incidence or severity of sustained injuries in the period before and after the introduction of speed limitation on 50 km/h.

The overall incidence of traffic accidents was 17650 in 1995. and 17281 in 1996. Since during the late spring and summer 1995. there were significant war activities which limited the amount of traffic in the whole country, we found it impossible to correlate the incidence of injuries by years, so we explored the incidence of accidents and their consequences by months, in order to see if there was any significant drawback in incidence and severity score after the implementation of a new, lower speed limit.

3. RESULTS

Analysis of incidence and severity of injuries sustained in traffic injuries before and after the implementation of speed limit legislation, had not shown any decrease in the incidence of traffic accidents. There was, in fact, increase in the incidence of traffic accidents after a one month delay. General count of injuries sustained was not changed, and followed the trend of the count of accidents. The amount of the most severe injuries with mortal injuries was not changed as well. These injuries happened mostly on the city speedways, where speed limit is higher then in metropolitan area, and where the exceeds of even this higher limit are rather the rule than the exception. Excesive drivers alcochol consumption was the other main cause of accidents in most of these cases.(Fig.2.)

When we analyzed the severity of sustained injuries, we found significantly decreased number of severe injuries.(Fig.1.) For the purpose of study, we divided injuries into those demanding hospitalization, and those in which a home care was sufficient way of treatment. After the implementation of speed limit legislation the number of injuries demanding stationary hospital treatment was significantly lower.(Fig.3.) This division showed even more obvious increment of light injuries, relieving a great deal of hospital facilities and staff.

4. DISCUSSION

Big cities are experiencing an exponential growth of incidence of injuries sustained in traffic accidents[15]. This situation led to various approaches intending to decrease as well the number of casualties as the severity of sustained injuries[11]. Although the accurate reconstruction of impact forces is difficult, and sometimes even impossible[9]. there are well documents reports suggesting that the increase, or decrease of speed limit has an impact on the incidence and severity of injuries in traffic accidents.[3,4,5,7,12,13,14,16]

Our results showed that the decrease of speed limit lead only to the temporary, limited decrease in the incidence of traffic accidents. That could be understood, for the traffic speed is only one of many factors leading to the traffic accident. Other factors, as are the condition of vehicle, drivers performance, weather and other circumstances are sometimes equally important. Being unable to act upon all levels of traffic safety (e.g. car construction, road construction) it is seemingly easier and cheaper to introduce a legislative regulation where possible. In our case it was the speed limit.

Although the accident incidence returned to previous values in the very short time interval, it was obvious that the injury severity remained lower than before the lowering the speed limit. Actually, severe injuries were swapped for light injuries with minimal permanent functional consequences. By our opinion this was not achieved exclusively by decrease of speed limit, but was, as a mater of fact result of many interconnected factors, as were better condition of vehicles, better control of technical security, routine use of safety seatbelts and reduced traffic speed as one of main factors. There remains the question of the effective impact of the legislation, for the traffic control gradually slackened few months after the implementation. Our results showed that the decrease of speed limit in urban area had a positive impact on injury severity, reducing mortality and morbidity resulting from those injuries, reducing absence from work and finally diminishing the possible permanent consequences and invalidity. Hospital capacities were significantly relieved from ever increasing amount of patients suffering from moderate injuries from traffic accidents, and have been able to provide better care for severely injures people, whose number unfortunately remained in same values as before. Therefore, we can conclude that with due regards to the shortness of observed time interval, a speed limitation bill had an overall positive impact on traffic safety in our circumstances.

SUMMARY:

EFFECTS OF SPEED LIMITS DECREASE IN 1996 ON INCIDENCE AND SEVERITY OF INJURIES SUSTAINED IN TRAFFIC ACCIDENTS IN THE CITY OF ZAGREB

PURPOSE: In July 1997. a new speed reduction bill was introduced in Croatia, imposing severe penalties for overspeeding. By new regulation a maximum speed for urban area was limited on 50 km/h. In this investigation we tried to establish the real impact of speed reduction on incidence and severity of injuries sustained in traffic accidents

METHOD: Data concerning incidence of traffic accidents obtained from Department of Traffic Security of Zagreb Police Administration were correlated with data collected from University Clinic for Traumatology in Zagreb, which was responsible for treatment of most of the victims from these accidents. Distinction was made between light, severe and fatal injuries, having in mind that severe injuries were burdened with possible residual handicap.

RESULTS: A sharp decrease in incidence and severity of injuries sustained in traffic accidents was noted during July and August 1997. Incidence of accidents subsequently increased, but the incidence of injuries, as well as their severity remained lower than before the implementation of the new bill.

CONCLUSION: A Speed Reduction Bill had a significant influence in reducing severity of injuries sustained in traffic accidents. Although the incidence of accidents gradually increased after initial drop, the average severity of injury remained lower than before it's introduction.

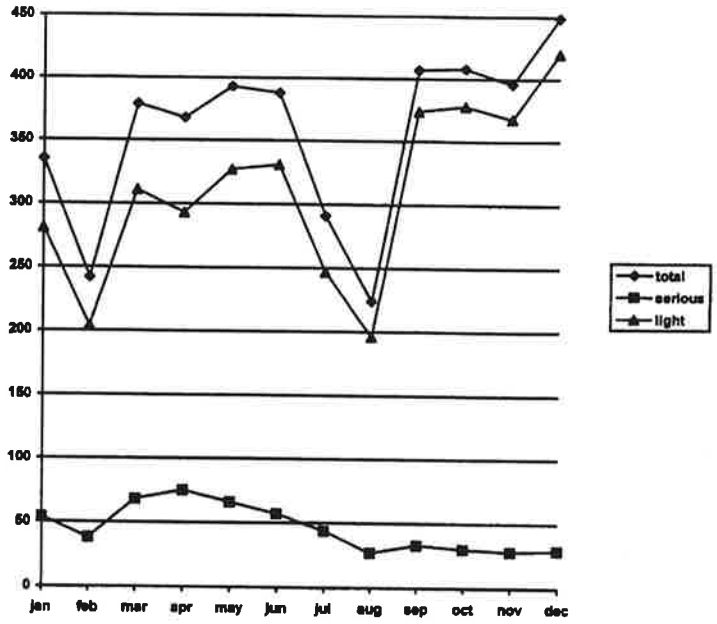


Fig.1. Injures in traffic accidents, Zagreb, 1996

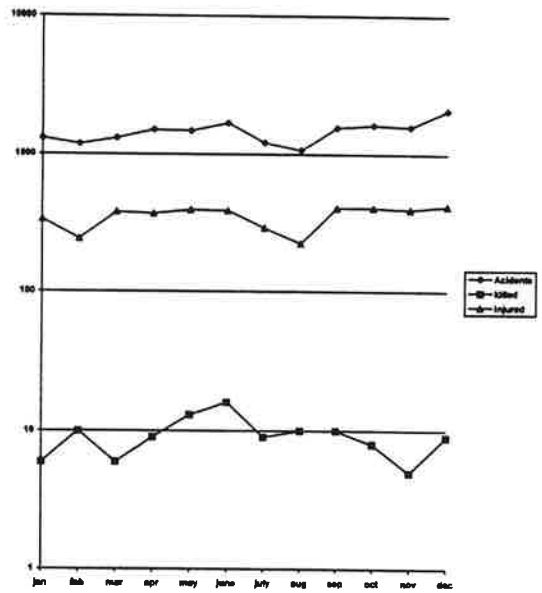


Fig.2. Injures vs. mortality in traffic accidents, Zagreb, 1996

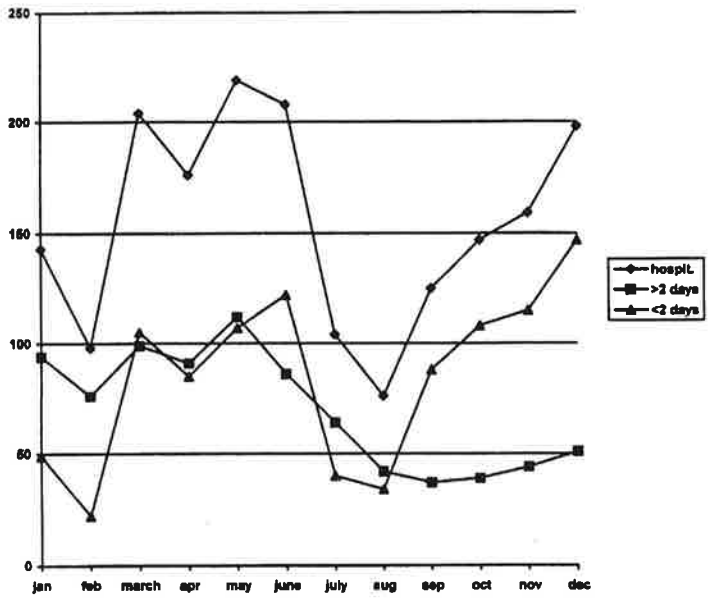


Fig.3. Hospitalization of light injures from traffic accidents, Zagreb, 1996

REFERENCES:

1. Bourbeau R, Desjardins D, Maag U, Laberge-Nadeau C: Neck injuries among belted and unbelted occupants of the front seats of cars. J Trauma 35:794-799, 1993

2. Bradbury A, Robertson C: Prospective audit of the pattern, severity and circumstances of injury sustained by vehicle occupants as a result of road traffic accidents. Arch Emerg Med 10:15-23, 1993

3. Engel U, Thomsen LK: Safety effects of speed reducing measures in Danish residential areas. Accid Anal Prev 24:17-28, 1992

4. Green RN, German A, Nowak ES, Dalmotas D, Stewart DE: Fatal injuries to restrained passenger car occupants in Canada: crash modes and kinematics of injury. Accid Anal Prev 26:207-214, 1994

5. Hakim S, Shefer D, Hakkert AS, Hocherman I: A critical review of macro models for road accidents. Acid Anal Prev 23:379-400, 1991

6. Jelčić I, Jelčić Ig., Mlačić M, Komanov I ed.: Prometni traumatizam. Med. Fakultet Sveučilišta u Zagrebu, 1992:19-21

7. Johansson P: Speed limitation and motorway casualties: a time series count data regression approach. Accid Anal Prev 28:73-87, 1996

8. Jones AP, Bentham G: Emergency medical service accessibility and outcome from road traffic accidents. Public Helath 109:169-177, 1995

9. Klehesberg D: Dezeitiger Stand der Verhaltensanalyse des Kraftfahrens. Arbeit und Leistung. Zblt fur Arbeitwissenschaft und Soziale Betriebspraxis. 18:2/3, 1964

10. Mackay GM, Hill JR: The limitations of current seatbelts in Europe. Some population considerations. J Trauma 38:533-537, 1995

11. Michalik C, Hoefner KJ: Die Erhebung von Verkehrskonflikten als Grundlagen Gezielter Massnahmen zur Verbesserung der Verkehrsicherheit. Hefte zu der Unfallchirurg 230:625-628, 1993

12. Moore VM, Dolins J, Woodward AJ: Vehicle speed and risk of severe crash. Epidemiology 6:258-262, 1995

13. Polem MR, Friedman GD: Automobile injury-selected risk factors and prevention in the health care. JAMA 259:76, 1988

14. Rock SM: Impact of 65 mph limit on accidents, deaths and injuries in Illinois. Accid

Anal Prev 27:207-214, 1995

15. Schenk E, Krause D, Klingheil M: Randomisierte Studie zur Epidemiologie des Verkehrsunfals einer Grosstadts aus chirurgischer und rechtmedizinicher Sicht. Hefte zu der Unfallchirurg 230:653-655, 1993

16. Wagenaar AC, Streff FM, Schulz RH: Effects of 65 mph speed limit on injury morbidity and mortality. Accid Anal Prev 22:571-585, 1990

17. Walz F: Biomechanische Aspekte bei Kollisionen im Strassenverkehr. Z Unfallchir Versicherungsmed 84:84-90, 1991

Raising the Speed Limit on Motorways - Is It Always a Bad Idea?

I. Hocherman*, A. Cohen**, & E. Doveh**

Introduction

On November 1994, the speed limit on motorways in Israel was raised from 90 kmh. To 100 kmh.. In practice, speed limit was raised on two stretches of road totaling 48 km, which qualified as motorways. This act followed a lengthy debate, and a period of slackening of police speed surveillance on these road sections.

Following the raise of the speed limit, a study was carried out to assess the effects of the change on both speeds and accidents on these two road segments, as well as on a third major highway with slightly lower standards, which retained the 90 kmh speed limit. This paper describes the accident analysis.

Planning the accident analysis the research team faced a multitude of problems - small numbers, changes in reporting practices, an uncertain break-point and possible intervening factors. To try and mitigate these problems, a number of different analysis were carried out. Basically, two different methods were used, Odds Ratio which compared the change in accidents, following the speed limit change, to the parallel change in a reference group, Poison Regression of the monthly series of accidents. Because of the different traffic and enforcement characteristics each of the segments, the analyses were done for each segment separately.

Data

The speed limit was raised on a 35 km segment on route 1 and 13 km on route 4. A control segment for which the speed limit was not raised, with geometric characteristics similar to those of the two motorway segments, was chosen on route 2. In addition, a reference group was defined, consisting of several segments of the interurban roads network, in which no massive construction work was done in the last few years.

Accidents data on a monthly basis, classified by severity, were obtained from the police for each one of the road segments. The police data base was incomplete before 1992, and thus the data (and the analysis) was limited to the years 1992 and onward.

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Methods

Separate analyses were carried out for all accidents, and for severe accidents only (including fatalities). Also, because the three segments had very different traffic and enforcement characteristics, separate analyses were done for each of the 3 segments.

Accident analysis consisted of two different statistical procedures: regression analysis, and Odds Ratio. Following is a brief description the two methods.

Odds ratio: The ratio of the number of accidents that occurred before and after the speed-limit change (SLC) for each road segment is compared with the same ratio for the reference group. The ratio of ratios is a statistical measure, called 'Odds Ratio' (R). For which a confidence interval can be estimated (e.g. Fliess "Statistical Methods For Rates and Proposition", Willey, 1973). In formal terms R is expressed as follows:

$$R = A_s/B_s : A_r / B_r$$

Where A_s = Number of accidents for road segment s after SLC.
B_s = Number of accidents for road segment s before SLC.
A_r = Number of accidents for the reference group after SLC.
B_r = Number of accidents in the reference group before SLC.

Odds ratios and confidence intervals were computed separately for each one of the two segments where the speed limit was raised (Routes 1 & 4), and for the highway segment in which SLC was not instituted (Route 2). These ratios were computed for a period of 18 months after, and 18 months before SLC. Care was taken to match these time windows seasonally. Thus, the post SLC period was 1.11.93 to 30.4.94 and the pre SLC period was 1.11.92 to 30.4.93.

In addition the possibilities that the effect of SLC on accidents rate occurred a few months before it was formally instated (due to publicity) or that it was delayed by a few months, were also tested by shifting the relevant time windows accordingly.

Poisson Regression: A regression model was constructed estimating the expected number of accidents for a given month, as a function of independent variables such as trend and season. The model also included an indicator variable for the event of SLC so that its effect on the model's intercept and slope could be determined. Several GLM regression models were tried and a Poisson model best fitted the actual data.

A separate regression model was constructed for each one of the road segments and for the reference group. The models were calibrated for the period of January, 1992 to April 1995. Five months, two before SLC and three afterwards, were omitted from the calibration period in order to allow for the possibility that the change in driving speed had occurred gradually, or had occurred before or after the actual change

Results

Odds Ratio: The results of this analysis, for each one of the studied sections, are shown in table 1 for different before and after time windows. The first post SLC time window consists of 15 months, starting on January of 1994 and ending on 30.4.1995. The other 3 time windows were 12 months long, with the first month of each after-SLC window moving sequentially from January to March of 1994. The before-SLC windows covered corresponding months during the years 1992 - 1993. Table 1 shows the number of accidents with injuries that occurred in each time window, the corresponding Odds Ratio and its confidence interval. Table 2 shows the same breakdown for severe accidents.

As can be seen, the results for the 3 road segments are different -
Highway #1: A near 1 Odds Ratio for all accidents and for severe accidents indicates no change in the rate of accidents after SLC, relative to the general trend in interurban roads.

Highway # 4: A 20% increase in the rate of accidents, relative to the reference group of interurban roads is indicated by an Odds Ratio of 1.2. However, this trend is not significant (Confidence Interval includes 1), and does not exist for severe accidents.

Highway #2: The Odds Ratio for all accidents is 1.10 and does not differ significantly from 1. However, there is a 100% (significant) increase in severe accidents, relative to the general interurban roads. This high Odds Ratio is due to a 50% increase in severe accidents on this section, paralleled by a decline in the rate of severe accidents in the reference sections.

Table 1: All Accidents

Highway #1

"before" period	"after" period	OR	L1	L2
1/92 - 3/93	1/94 - 3/95	0.98	0.82	1.17
1/92 - 12/92	1/94 - 12/94	0.94	0.77	1.14
2/92 - 1/93	2/94 - 1/95	0.97	0.79	1.18
3/92 - 2/93	3/94 - 2/95	1.06	0.87	1.30
4/92 - 3/93	4/94 - 3/95	1.02	0.84	1.25

Highway #4

"before" period	"after" period	OR	L1	L2
1/92 - 3/93	1/94 - 3/95	1.19	0.89	1.59
1/92 - 12/92	1/94 - 12/94	1.13	0.82	1.56
2/92 - 1/93	2/94 - 1/95	1.17	0.85	1.62
3/92 - 2/93	3/94 - 2/95	1.29	0.92	1.79
4/92 - 3/93	4/94 - 3/95	1.26	0.90	1.76

Highway #2

"before" period	"after" period	OR	L1	L2
1/92 - 3/93	1/94 - 3/95	1.07	0.84	1.36
1/92 - 12/92	1/94 - 12/94	0.99	0.76	1.30
2/92 - 1/93	2/94 - 1/95	1.13	0.86	1.47
3/92 - 2/93	3/94 - 2/95	1.10	0.84	1.43
4/92 - 3/93	4/94 - 3/95	1.15	0.88	1.50

OR - Odds Ratio; L1, l2 - lower and upper confidence interval limits

Table 2: Severe accidents

Highway #1

"before" period	"after" period	OR	L1	L2
1/92 - 3/93	1/94 - 3/95	0.89	0.52	1.53
1/92 - 12/92	1/94 - 12/94	0.90	0.49	1.66
2/92 - 1/93	2/94 - 1/95	0.95	0.52	1.73
3/92 - 2/93	3/94 - 2/95	1.18	0.64	2.17
4/92 - 3/93	4/94 - 3/95	1.07	0.59	1.97

Highway #4

"before" period	"after" period	OR	L1	L2
1/92 - 3/93	1/94 - 3/95	1.07	0.47	2.41
1/92 - 12/92	1/94 - 12/94	1.05	0.43	2.57
2/92 - 1/93	2/94 - 1/95	0.89	0.36	2.20
3/92 - 2/93	3/94 - 2/95	0.93	0.39	2.22
4/92 - 3/93	4/94 - 3/95	1.07	0.46	2.49

Highway #2

"before" period	"after" period	OR	L1	L2
1/92 - 3/93	1/94 - 3/95	1.84	1.07	3.16
1/92 - 12/92	1/94 - 12/94	1.96	1.10	3.47
2/92 - 1/93	2/94 - 1/95	2.37	1.30	4.31
3/92 - 2/93	3/94 - 2/95	2.17	1.18	4.01
4/92 - 3/93	4/94 - 3/95	2.25	1.22	4.14

OR - Odds Ratio; L1, l2 - lower and upper confidence interval limits

Poisson Regression:

The model which best fits the accidents data is of the form

$$\text{Log } \lambda_I = \Sigma \beta_i X_{ij}$$

where λ_I is the expected number of accidents in location I, X_{ij} are independent variables and β_I are regression coefficients. The independent variables included the sequential observation number, total interurban traffic volume, an economical variable (private per capita consumption) and 4 seasonal variables. The traffic volume data for each one of the road segments turned out to be unstable and therefore useless for modeling purposes. On the other hand, the three trend variables were highly correlated (and thus only one of them can be included in the model). Of these, the observation number turned out to be the best indicator of the trend and therefore was included in all of the models. This variable describes a linear trend of the Logarithm of accidents number, or an exponential trend of the actual accidents series.

In addition, seasonal variables were also found to have a significant impact on the number of accidents, and thus were included in the model.

Indicator variables for the speed change included a dichotomous variable estimating a constant effect of SLC (change in intercept) and an interaction term with the observation no. which estimates a change in the slope.

The model for the reference group has not indicated any effect of the change in speed limit- neither on the total no. of accidents nor on severe accidents .
For Route 1 the model depicts a non-significant increase in total accidents, but not for severe accidents.
On Route 4 there was a significant decrease in the number of severe accidents following SLC.

On Route 2 the models depicts an increase in both the total and severe no. of accidents, though the increase in severe accidents is not significant (p=0.11).

Table 3: Regression analysis results - effect of SLC

Road Segment	Total No. of Accidents	Severe Accidents
Highway #1	Non-sig. rise in intercept	No Change
Highway #4	No Change	Sig. Decline in Intercept
Highway #2	Significant rise in slope	Non-sig. rise in intercept
Reference group	No Change	No Change

Discussion

The results, in a nutshell, show no change in accidents for the two segments where the speed limit was raised (routes 1 &4).

On Route 1 the Odds Ratios are all around 1 and non-significant, and the regression results did not depict a change in accidents.

On Route 4, an increase of 20% in total accidents (though not significant) was found using the OR method. However, there was no similar increase in the severe accidents, as could have been expected if this increase was due to an increase in travel speeds. Also, the regression analysis did not back up this finding. On the contrary, the regression results showed a decrease in severe accidents after the change.

The only segment for which there is an indication of an effect of SLC is Route 2, where the speed limit was not changed. Both methods show significant effect of the speed change, though the effects are not the same - the OR method indicated a major change in severe accidents, while the regression analysis depicted a significant change in total accidents. The meaning of these findings is not clear. It may mean that the speed limit change effected driving habits on this segment, although it was not instigated there (in fact, many people believed it was, due to the similarity in geometric characteristics). Alternatively, the increase may be due to other factors, not connected to the SLC. The

second explanation seem more plausible considering the "no change" findings for the two motorway segments.

The no-change finding for the reference group using the regression analysis may be expected, considering the findings for the motorway segments. It also negates the hypothesis that the SLC had an overall or "spill-over" effect, which may mask an increase in accidents on the motorways, when relative methods such as OR are used.

The findings may best be explained by examining speed data. In the current study speeds were measured only after the change in speed limit was instated. Mean and median speeds on all three high-way segments were around 100kmh. However, results from other speed studies suggest that the same speeds existed even before the speed limit was raised. Speeds were rising gradually as roads improved and vehicles became faster. The legal change as such had no effect on the speeds - it did not change the norm, but rather it adjusted the legal norm to the social one. This does not mean that traffic laws have no effect or that speed limits are useless. The more interesting questions of when and under what circumstances laws can have an effect on traffic behavior, and whether it is possible to change social norms rather than adjust to them, is beyond the scope of this paper.

CHARACTERISTICS OF SOME ACCIDENT CIRCUMSTANCES ON ROAD BLACKSPOT SECTIONS

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1 Introduction

Accidents are a consequence of various aspects of road, vehicle and road user. They are scarce over time and space. Sometimes there is no initial indicaton why accidents cluster at certain locations and what particular circumstances accompany accidents at these locations. Any inferences drawn from systematical statistical analysis of accident data can be of great importance in accident investigation, leading to the provision of suitable remedial countermeasures to improve road safety.

In order to identify hazardous sections of a road the Bayesian approach has been utilized in the paper. The total numbers of: fatalities, injuries and vehicles involved in accidents along a road section are considered as they represent accident severity. The probabilities of the occurences of these accident quantitative features with respect to the fact that parameters of the respective distributions are random variables have been defined. On the basis of these probabilities as well as on the basis of the length of the road section a weight is given to the section. The weight is a measure of the level of accident risk of the section. The measure greater than a certain threshold value identifies the section as a blackspot one.

Accident details are included in road police reports. The majority of the details are qualitative features. Some of them have been chosen to find out possible accident problems characteristic to blackspot sections. Algorithms of qualitative analysis are applied to systematize the information, to identify typical characteristics of a specified accident feature and to find out associations between the features and between their classification categories.

2 The method of blackspot sections identification

To perform the road safety analysis, road sections characterized by grouping of accidents are determined first. This is done by applying one of methods of clustering analysis. To identify a blackspot section among accident cluster sections, which are the result of clustering analysis, an accident-proness model has been elaborated [Tracz and Nowakowska; 1996]. The model describes distributions of some quantitative accident variables. As the model is based on the Bayesian approach [Benjamin and Cornell; 1977] the method of blackspot sections identification is called a Bayesian one. The model is based on two sources of information. The first one $h(x)$ is a prior distribution of the accident variable X over accident cluster sections:

$$h(x)=\begin{cases}(s/(1+s))^k & \text{for } x=0\\ h(x-1)\cdot(x-1+k)/(x\cdot(1+s)) & \text{for } x\geq 1\end{cases} \tag{1}$$

The second source $\tilde{h}(x|z,i)$ is a posterior distribution of X variable which can occur at those sections, where the variable value of z over i time units has been recorded:

$$\tilde{h}(x|z,i)=\begin{cases}((i+s)/(i+1+s))^{z+k} & \text{for } x=0\\ \tilde{h}(x-1|z,i)\cdot(x-1+z+k)/(x\cdot(i+1+s)) & \text{for } x\geq 1\end{cases} \tag{2}$$

In the above distributions $s>0$ is a scale parameter and $k>0$ is a shape parameter.

The safety of a road section is characterised by the following set of weights:

$$S=\{W(X_1),\ W(X_2),\ W(X_3),\ LW(l)\} \tag{3}$$

The variable X_i identifies the number of i-th accident variable as follows: X_1 is the number of injured people, X_2 is the number of people killed, X_3 is the number of vehicles involved in accidents. The weight $W(X)$ is defined by the expression (4):

$$W(X)=\sum_{m+1}^{\infty}\tilde{h}(x|z,i)dx \qquad \text{where: } \sum_{0}^{m}h(x)dx\approx\sum_{m}^{\infty}h(x)dx\approx 0.5 \tag{4}$$

The element $LW(l)$ of the set S is the weight of a section length:

$$LW(l)=\begin{cases}-0.5\cdot l^2+1 & \text{for } l\in<0,1>\\ 0.5\cdot(l-l_{max})^2/(l_{max}-1)^2 & \text{for } l\in<1,l_{max}>\end{cases} \tag{5}$$

A section classification value SW has been defined to proceed the identification:

$$SW=\sqrt{\sum_j W(X_j)^2+LW(l)^2} \tag{6}$$

A blackspot criterion is determined by a critical set S^* of the elements equal to 0.5, 0.4, 0.6 and 0.75. These values reflect the rank of respective elements of the set S. An accident cluster section is indicated as a hazardous one, i.e. a blackspot section, if its classification value SW is greater than the value (6) for the critical set S^*.

3 Qualitative analysis

Accident details are included in road police reports called Road Accident Cards. This information is collected and stored in computer database files. The majority of fields of such files are of descriptive character like driver's behaviour for example. Qualitative analysis was applied to systematize the descriptive information and to characterize accident qualitative features and their combinatons. The analysis is based on cross-classification (contingency) tables.

Describing the set of qualitative features can be processed on the basis of some statistical measures [Góralski; 1979]. Modal category M is the feature value to which the majority of the set observations belongs. It characterises the most typical property of the set and is defined as follows:

$$M = max\{n_i, \quad i = 1,2,\ldots,k\} \tag{7}$$

Dispersion of classification coefficient enables to evaluate the degree of homogenity of the set. The range of the dispersion coefficient is the interval <0, 1>. The value h=0 confirms full homogeneity of the set. The value h=1 presents the evidence of full heterogeneity of data. The dispersion coefficient is a measure of the form:

$$h = 2\left(\sum_{i=2}^{k}(i-1)\cdot c_i\right)/(k-1) \qquad c_{i-1} \geq c_i \tag{8}$$

In the formulas (7) and (8): i is the number of the i-th feature category, n_i is the number of observations that belong to the i-th category, k is the number of categories of a considered feature, c_i defines sequence of frequencies of feature categories ordered in a not ascending way: $c_i = n_i / N$, N is a sample size.

Associations in a cross-classification table is investigated by testing null hypotheses H_0 of no association [Agresti;1984]. A general association can be tested by the χ^2 Pearson's test with a test statistic of the following form:

$$\chi^2 = \sum_i \sum_j (n_{ij} - m_{ij})^2 / m_{ij} \tag{9}$$

where: n_{ij} is the number of observations of the i-th category of the first feature and the j-th category of the second feature and m_{ij} is the expected number of observations of the categories combination as above, provided that the H_0 is true. The statistic (9) is asymptotically (as $N \to \infty$) χ^2 distributed with degrees of freedom $DF = (r-1)(c-1)$.

The association between categories in a cross-classification table cell can be evaluated on the basis of the relevance of surpluses or deficiencies in the cell [Góralski; 1979]. To ascertain if the surplus or deficiency is relevant the value of ψ^+ or ψ^- statistic for the ij-th cell is calculated:

$$\psi^{sgn(n_{ij}-m_{ij})} = \left|n_{ij} - m_{ij}\right| / \left\{\sqrt{1 + \left(m(m-K-1)\right)/K^m} \cdot \sqrt{m_{ij}(1 - m_{ij}/N)}\right\} \tag{10}$$

where, the sgn function determines surplus (+) or deficiency (–) of the number of observations, $K = max\{k_1, k_2\}$, k_1, k_2 are the numbers of categories of the first and the second feature respectively and m is the number of considered features; in this paper m=2. The null hypothesis is rejected if the value (10) is greater than a ψ critical value, tabulated elsewhere [Góralski; 1966].

4 An experiment

Information about accidents, involving death or injury, recorded during the years 1991-1995 on roads of two neighbouring provinces of south-central Poland was the source of data for the experiment of searching for connections between accident features on road blackspot sections. Among 61 roads (rural and of non urban traffic character) four have been chosen as the subject of the experiment. Some characteristics of these roads and the results of the process of blackspot sections identification are presented in the table 4.1.

Only one blackspot section with fifteen observations was identyfied on the road No 728. Conclusions for that section have been given up. In addition, results obtained for the roads No 44 and No 74 are interpreted for small sample sizes.

Table 4.1. Some accident statistics of road blackspot sections.

Road number	Road category	The length of the road [km]	Number of accidents on the road	Blackspot sections information		
				Number of the sections	Total length [km]	Number of accidents
-1-	-2-	-3-	-4-	-5-	-6-	-7-
7	international	192.2	1318 (2.3)	31	39.0	716 (3.7)
44	interregional	84.5	376 (1.5)	6	14.6	145 (2.0)
74	interregional	82.1	393 (1.3)	3	8.7	103 (2.4)
728	regional	146.0	258 (0.6)	1	2.6	15 (1.2)

Average accident densities (number of accidents/km/year) are given in brackets.

Nine qualitative features that describe accident circumstances are included in the Road Accident Card. Some of them were chosen for closer investigation to identify possible accident problems characteristic to road blackspot sections: ACCIDENT TYPE that has 11 categories, PEDESTRIAN'S BEHAVIOUR with 20 categories and DRIVER'S BEHAVIOUR with 16 categories. The significance of presence of alcohol in road users' blood has also been examined.

The percentage of accidents with pedestrians in the considerded region of Poland was very high. It exceeded 30% and close to 20% of injured and over 38% of killed in accidents were pedestrians during the years 1991-1995. Subsets of data including only *Hitting pedestrian* accident type were created and further analysis where „pedestrian" features are involved concerns these subsets.

4.1 Statistical characteristics of some qualitative accident features

Some results of statistical analysis of descriptive accident features are presented in the table 4.2. On the basis of them it can be said that:

- Most frequent accident types are common for all analysed roads. Their distributions are just the same for both a chosen road and its blackspot sections (see table 4.2.A). The category *Hitting pedestrian* is a median one for all cases. It occured even in every third accident. The values of dispersion coefficient show the tendency to the differentiation of the set within the feature.

– Three groups of categories represent DRIVER'S BEHAVIOUR in the table 4.2.B. The order of these groups is in principle the same not only within a road and its sections but also within all cases (compare columns 2, 3, 4, 6, 7 of the table 4.2.B). The medians are different for blackspot sections of different roads. Values of dispersion coefficient evidence the concentration tendency of the feature, taking into acount that there are twenty possible driver's behaviour.

Table 4.2. Most frequent categories of three accident features.

The category of accident feature	Ratio of the number of accidents of a category to the total number of accidents[%]							
	road	sections	road	sections	road	sections	road	sections
- 1 -	-2-	-3-	- 4 -	- 5 -	- 6 -	- 7 -	- 8 -	- 9 -
	Roan No 7		Road No 44		Road No 74		Road No 728	
A. Most frequent accident types								
• Hitting pedestrian	26.6	28.8	23.7	24.7	30.3	40.8	29.8	20.0
• Head on collision	19.9	20.9	18.9	18.6	15.8	10.7	16.3	26.7
• Rear-end collision	18.1	16.6	20.5	20.7	15.3	15.5	17.1	40.0
• Side collision	12.8	13.1	13.3	13.8	10.9	11.7	14.0	13.3[1]
Total [%]	**77.4**	**79.4**	**76.4**	**74.5**	**72.3**	**78.6**	**77.2**	**100**
Dispersion [–]	**0.43**	**0.41**	**0.44**	**0.44**	**0.45**	**0.34**	**0.42**	**0.213**
B. Most frequent driver's behaviours								
• Nothing particular • Inattenation, distraction, imprudence • Tiredness, falling asleep	31.9	32.0	30.4	25.4	29.7	42.7	33.3	13.3
• Mismatching the speed to a traffic situation, • Exceeding speed limit	23.8	24.4	21.6	25.5	26.2	22.3	21.3	13.3
• Incorrect overtaking or passing round	10.8	10.5	14.1	12.4	14.2	6.8	14.7	33.3
Total [%]	**66.5**	**66.9**	**66.4**	**63.3**	**70.1**	**71.8**	**69.3**	**59.9**
Dispersion [–]	**0.38**	**0.37**	**0.37**	**0.37**	**0.35**	**0.33**	**0.33**	**0.24**
C. Most frequent pedestrian's behaviours								
• Enter a roadway before a moving vehicle	47.1	44.2	29.2	29.0	44.1	31.0	32.5	66.6
• Nothing particular	30.9	29.6	31.5	29.0	26.1	26.2	32.5	33.3
• Running across a roadway	8.3	12.1	9.0	8.5[2]	6.8	9.5	7.8[2]	33.3[2]
• Children up to seven running onto a rodway	2.6	3.9	12.4	16.1	5.9	14.3	6.5	0.0
Total [%]	**88.9**	**89.9**	**82.1**	**80.6**	**82.4**	**80.6**	**79.3**	**100**
Dispersion [–]	**0.16**	**0.17**	**0.24**	**0.24**	**0.22**	**0.25**	**0.24**	**–**
D. Presence of alcohol in driver's blood								
Yes	5.0	5.0	3.7	3.4	12.0	10.7	7.8	6.7
Dispersion [-]	**0.10**	**0.1**	**0.08**	**0.07**	**0.24**	**0.21**	**0.16**	**0.13**
E. Presence of alcohol in pedertrian's blood								
Yes	27.1	30.1	21.3	22.6	36.1	38.1	19.5	66.7
Dispersion [–]	**0.55**	**0.60**	**0.43**	**0.45**	**0.72**	**0.76**	**0.39**	**0.67**

The following categories instead of the categories referenced in relative rows are represented in the bold, dark framed cells of the table:

[1] Rolling over
[2] Walking along a wrong side of a roadway
[3] Standing or falling down on a roadway

- The accidents of the type *Hitting pedestrian* are concentrated on two categories of the PEDESTRIAN'S BEHAVIOUR feature: *Enter a roadway before a moving vehicle* and *Nothing particular*. The concentration is confirmed by the dispersion coefficient, which does not exceed the value of 0.25 in any case.
- Results for the feature PRESENCE OF ALCOHOL IN PEDERTRIAN'S BLOOD are significant. Irresponsible behaviour of pedestrians being under the influence of alcohol may be one of the most important reasons of road accidents.

4.2 Association between some qualitative accident features

Preparatory analyses of cross-classification resulted in contingency tables of very small cell frequences. In order to obtain tables having larger cell frequences some categories of the features were combined, which is commonly done by researches [Agresti; 1984]. New created categories and thier definitions are given in the table 4.3. Results of general association tests for combinations of two qualitative features are presented in the table 4.4. Some results of tests of associations between categories of analysed features are presented in the tables 4.5, 4.6 and 4.7. There are the following abbreviations for the features there: DB is DRIVER'S BEHAVIOUR, AT is ACCIDENT TYPE, PB is PEDESTRIAN'S BEHAVIOUR and AP is PRESENCE OF ALCOHOL IN PEDESTRIAN'S BLOOD.The interpretation is done at the common type I error rate α=0.05.

Table 4.3. New classifications of categories for three accident features.

Old values	New value	New classification category
- 1 -	- 2 -	- 3 -
A. ACCIDENT TYPE		
1	1	Head on collision
2	2	Side collision
3	3	Rear-end collision
4	4	Hitting pedestrian
5, 7, 8, 9	5	Hitting object on carriageway
6	6	Hitting fixed object
10	10	Rolling over
11	11	Others
B. DRIVER'S BAHAVIOUR		
0, 17, 18	0	Late driver's reaction
1, 2	1	Excessive speed
3,10	3	Disobeying priority
4,5,7	4	Incorrect manoeuvres of a driver
6	6	Incorrect crossing a pedestrian crosswalk
8	8	Incorrect vehicle stoppage or parking
9	9	Keeping the wrong side of a roadway
12, 13	12	Too close distance between vehicle
14, 15	14	Sudden changing of speed (external traffic situation)
16	16	Dazzling a driver by another vehicle
11, 19	19	Disobeying other traffic regulations
C. PEDESTRIAN'S BEHAVIOUR		
0, 15	0	Indefinable pedestrian's fault
1	1	Standing or falling down on a roadway
2	2	Walking along the wrong side of a roadway
3,4,5	3	Incorrect crossing a roadway
6, 7, 8, 9, 10	6	Incorrect enter a roadway
11, 12, 13	11	Children up to seven entering a roadway
14	14	Falling in/from vehicle

Table 4.4. Results of tests of general association between two features.

Road number	Sample size	χ^2		% of cells of expected counts < 5	DF
		Value	Prob.		
- 1 -	- 2 -	- 3 -	- 4 -	- 5 -	- 6 -
A. Driver's behaviour x Accident type					
7	716	898.05	0.001	60	70
44	145	223.79	0.001	90	56
74	103	127.97	0.001	93	56
B. Pedestrian's behavoiur x Driver's behaviour					
7	206	121.04	0.001	88	35
44	31	18.19	0.259	92	15
74	42	29.10	0.09	93	20
C. Presence of alcohol in pedestrian's blood x pedestrian's behaviour					
7	197	34.86	0.001	40	4
44	26	7.06	0.133	80	4
74	36	13.08	0.011	60	4
D. Presence of alcohol in pedestrian's blood x Presence of alcohol in driver's blood					
7	197	0.374	0.541	25	1
44	26	0.798	0.372	50	1
74	36	1.286	0.257	50	1

Table. 4.5. Significant relationships between some categories of the features: DRIVER'S BEHAVIOUR (DB) and ACCIDENT TYPE (AT).

		Road No 7 black sections			Road No 44 black sections			Road No 74 black sections		
DB	AT	n_{ij}	m_{ij}	ψ	n_{ij}	m_{ij}	ψ	n_{ij}	m_{ij}	ψ
- 1 -	- 2 -	- 3 -	- 4 -	- 5 -	- 6 -	- 7 -	- 8 -	- 9 -	- 10 -	- 11 -
Significant surpluses										
		ψ_α=1.63			ψ_α=1.60			ψ_α=1.58		
0	4	160	65.9	13.32	25	7.5	7.34	31	17.9	3.79
1	10	20	8.1	4.59	8	4.3	1.99	4	1.7	2.19
1	6	30	11.8	5.83	10	4.1	3.32	5	2.5	1.83
1	1	45	34.8	1.95						
3	2	59	9.5	17.76	11	2.1	6.98	6	0.7	7.10
4	3	31	15.5	4.37	9	4.6	2.36			
4	1	32	19.5	3.15						
6	4	8	2.3	4.12						
9	1	13	2.9	6.45						
12	3	42	11.1	10.20	6	2.3	2.78	4	1.1	3.13
12	2	15	8.8	2.30						
14	1	22	7.3	5.96	6	3.2	1.79			
Significant deficiences										
		ψ_α=1.66			ψ_α=1.70			ψ_α=1.71		
0	2	1	30.1	5.93	0	4.8	2.49	0	5.1	2.59
0	3	10	38.1	5.11	3	7.2	1.81	1	6.8	2.58
0	1	16	48.0	5.23						
0	10	6	11.2	1.71	1	4.1	1.74			
1	2	7	21.8	3.52	1	5.1	2.06	0	2.7	1.85
1	4	15	47.8	5.37	3	7.9	2.00			
3	4	0	20.7	5.06	0	3.2	2.02	0	2.4	1.76
3	3	0	12.0	3.82	0	3.1	1.99			
3	5	0	4.5	2.34						
3	6	1	5.1	2.00						
4	6	0	6.6	2.8	0	2.4	1.75			
4	4	12	26.8	3.18	1	4.7	1.94			
4	10	1	4.5	1.83						
12	4	0	19.3	4.87	0	2.4	1.73	0	2.9	1.91
12	1	5	14.0	2.67						
12	6	0	4.8	2.40						
14	4	2	10	2.80	0	3.7	2.16			
14	3	0	5.8	2.65						

Table. 4.6. Significant relationships between some categories of the features: PEDESTRIAN'S BEHAVIOUR (PB) and DRIVER'S BEHAVIOUR (DB) for *Hitting pedestrian* acident type.

		Road No 7 black sections			Road No 44 black sections			Road No 74 black sections		
PB	DB	n_{ij}	m_{ij}	ψ	n_{ij}	m_{ij}	ψ	n_{ij}	m_{ij}	ψ
- 1 -	- 2 -	- 3 -	- 4 -	- 5 -	- 6 -	- 7 -	- 8 -	- 9 -	- 10 -	- 11 -
Significant surpluses										
		ψ_α=1.62			ψ_α=1.44			ψ_α=1.48		
0	1	15	4.6	5.56	3	0.87	2.72			
0	4	10	3.7	3.77	1	0.29	1.56	4	1.2	2.96
0	6	8	2.4	4.04						
0	19	6	2.1	3.00						
3	0	93	73	3.29						
Significant deficiences										
		ψ_α=1.68			ψ_α=1.82			ψ_α=1.80		
0	0	20	48.9	5.36				4	9.6	2.42
3	1	0	6.8	3.01						
3	4	0	5.5	2.68						

Table. 4.7. Significant relationships between some categories of the features: PRESENCE OF ALCOHOL IN PEDESTRIAN'S BLOOD (AP) and PEDESTRIAN'S BEHAVIOUR (PB) for *Hitting pedestrian* acident type.

		Road No 7 black sections			Road No 44 black sections			Road No 74 black sections		
AP	PB	n_{ij}	m_{ij}	ψ	n_{ij}	m_{ij}	ψ	n_{ij}	m_{ij}	ψ
- 1 -	- 2 -	- 3 -	- 4 -	- 5 -	- 6 -	- 7 -	- 8 -	- 9 -	- 10 -	- 11 -
Significant surpluses										
		ψ_α=1.62			ψ_α=1.41			ψ_α=1.46		
0	0	60	43.3	3.38				12	7.2	2.41
1	3	44	29.4	3.42						
1	1	4	1.9	1.83						
1	6							4	2.2	1.49
Significant deficiences										
		ψ_α=1.68			ψ_α=1.83			ψ_α=1.81		
0	3	50	64.6	2.60						
1	0	3	19.7	4.67	0	2.4	1.98	1	5.8	2.60

General association – table 4.4. The significance level for testing independence of the combination of the features DRIVER'S BEHAVIOUR and ACCIDENT TYPE is less than 0.05 for all cases. Hence there is some evidence of an association. Looking at the numbers in the parts B and C of the table 4.4 one can say of the association between the respective features for blackspot sections of the road No 7 and the lack of association for blackspot sections of the road No 44. Very slight associations can be considered for the sections of the road No 74 – P-values are equal to 0.09 and 0.011 for the features combinations in the parts B and C of the table 4.4. As can be seen in the table 4.4.D the fact that both a driver and a pedestrian were under the influence of alcohol when an accident occured is a coincidence as there is no evedence to reject H_0.

Tests of associations between categories of qualitative features – tables 4.5, 4.6, 4.7. Test statistics ψ calculated from data are given in the columns 5, 8 and 11 of the tables. Those combinations of categories are put in the tables for which the n_{ij} numbers for significant surpluses were not less than 5 and the m_{ij} numbers for significant deficiencies were not less than 5. Hovever, there are some exceptions given for comparison. They are marked gray in the tables. There are surpluses between five combinations of DRIVER'S BEHAVIOUR and ACCIDENT TYPE that are significant for blackspot sections of the three roads.

Particular drivers' behaviours can cause accidents of certain types independently of the category and the function of a road (table 4.5). These are:

- *Hitting pedestrian* (AT=4) coincided meaningly with a driver's behaviour about which is hardly to say it is admittedly in fault (DB=0),
- *Excessive speed* (DB=1) usually results in *Rolling over* or *Hitting fixed object* (AT=10 and AT=6 respectively),
- *Disobeying priority* (DB=3) ends in *Side collision* (AT=2) more often than one could expected,
- *Rear-end collisions* (AT=3) caused by *Too close distance between vehicles* (DB=12) confirms common expectations about this kind of association.

Significant surpluses were also found out between other combinations of categories but not for blackspot sections of all roads:

- *Head on collision* category (AT=1), which is considered the most dangerous accident type, can be a consequence of the following behaviours of a driver:
  a) *Sudden changing of speed* (DB=14); sections of the roads No 7 and No 44,
  b) *Excessive speed* (DB=1), *Incorrect manoeuvres of a driver* (DB=4), *Keeping the wrong side of a roadway* (DB=9); sections of the road No 7.
- In the case of the roads No 7 and No 44 there is dependency between *Incorrect manoeuvres of a driver* (DB=4) and *Rear-end collision* accident type (AT=3).
- *Too close distance between vehicles* (DB=12) caused not only *Rear-end collisions* (AT=3) but also *Side collisions* (AT=2) on blackspot sections of the road No 7.

Some types of accidents usually cannot be connected with certain driver's behaviour on considered road blackspot sections – this is confirmed by significant deficiences obtained for the combinations of categories that are referenced to in the columns 1 and 2 of the table 4.5.

Particular attention should be focused to *Hitting pedestrian* accidents. Numbers in the table 4.5 show that it could be hardly say about evident driver's fault (DB=0) in that type of accidents for blackspot sections of all roads. However, tests of associations can give a bit different results for conditional probabilities [Agresti; 1984]. So looking at the contens of the table 4.6 it can be stated that:

- *Incorrect crossing a roadway* (PB=3) coincides significantly with mentioned earlier driver's behaviour (DB=0) for blackspot sections of the road No 7,
- a pedestrian could become a victim (PB=0) of the following behaviours of a driver for some of the blackspot sections: *Excessive speed* (DB=1), *Incorrect manoeuvres of a driver* (DB=4), *Incorrect crossing a pedestrian crosswalk* (DB=6) and *Disobeying other traffic regulations* (DB=19).

Presence of alcohol in pedestrian's blood infulences significantly particular pedestrian's behaviour such as (see table 4.7): *Incorrect crossing a roadway* or *Incorrect enter a roadway* (PB=3 and PB=6 respectively) or *Standing or falling down on a roadway* (PB=2). In accidents with pedestrian if a pedestrian was under the influence of alcohol usually the guilt was on his side – see significant deficiences for the combination AP=1 and PB=0.

5 Final remarks and conclusions

The analysis of some circumstances which accompanied acccidents that had occured along blackspot sections on some roads in Poland has been presented in the paper. The blackspot sections were identified on the basis of Bayesian approach, that enables to take into account randomness of accident occurence in time and space. In order to identify typical characteristics of certain descriptive accident features qualitative analysis has been used. Some conclusions that concern the analysis are presented below.

- Not long time interval of collecting accident data should be taken to the process of blackspot sections identification in order to keep the information up-to-date. On the other hand statistical characteristics and searching for associations between qualitative features involve quite a big sample size and consequently a longer time interval of data registration.
- There are too many categories defined for some features in Road Accident Card. What is more they are not separate and not independent one of another within a feature. As a consequence a policeman can have doubts while evaluating a feature category. In addition cross-classification of such data could be difficult. In order to obtain more coherent classification some suggestions of new categories have been put forward for three qualitative features: ACCIDENT TYPE, DRIVER'S BEHAVIOUR and PEDESTRIAN'S BEHAVIOUR.
- Results of tests of associtations for cross-classification of qualitative features depend on a road, its category and function.
- Tests of associations have confirmed a crucial role of excessive speed not only in head on collisions but also in other accident types such as: rolling over, hitting fixed object and hitting pedestrian.
- Extremally high number of accidents relates to accidents with pedestrians. This is connected with too easy access to a road from a neighbour and with the lack of separation of local both pedestrian and vahicular traffic with transit traffic.

References

1. Agresti A. (1984). Analysis of Ordinal Categorical Data. John Wiley & Sons, Inc., New York.
2. Benjamin J. and A. Cornell (1977). Rachunek prawdopodobieństwa, statystyka matematyczna i teoria decyzji dla inżynierów. WNT, Warszawa.
3. Góralski A. (1966). Kryterium ψ oceny istotności nadwyżki i niedoboru liczebności w elementarnej kostce wielodzielczej m-wymiarowej tablicy. Zeszyty Naukowe Politechniki Warszawskiej, Warszawa.
4. Góralski A. (1979). Algorytmy i programy statystyki kwalitatywnej. Wydawnictwa Naukowo-Techniczne, Warszawa.
5. Tracz M. and M. Nowakowska (1996). Bayesian Theory and Cluster Analysis in the Identification of Road accident Blackspots. 13-th International Symposium on Transportation and Traffic Theory, Lyon, 24-26 July.

Appendix

TABLE A. Classification categories of some qualitative accident features in Road Accident Card.

Classification category	Numerical value of the classification category
- 1 -	- 2 -
ACCIDENT TYPE	
Head on collision	1
Side collision	2
Rear-end collision	3
Hitting pedestrian	4
Hitting a standing (immobilized) vehicle	5
Hitting fixed object	6
Hitting railway barrier	7
Hitting road device	8
Hitting animal	9
Rolling over	10
Others	11
DRIVER'S BEHAVIOUR	
Nothing particular	0
Exceeding speed limit	1
Mismatching the speed to a traffic situation	2
Disobeying right of way regulations	3
Incorrect overtaking or passing round	4
Incorrect passing	5
Incorrect crossing a pedestrian crosswalk	6
Incorrect turning	7
Incorrect vehicle stoppage or parking	8
Keeping the wrong side of a roadway	9
Entering red signal	10
Disobeying other road signals and signs	11
Following too closely	12
Barring one's way	13
Skidding	14
Sudden braking	15
Dazzling a driver by another vehicle	16
Inattenation, distraction, imprudence	17
Tiredness, falling asleep	18
Others	19
PEDESTRIAN'S BEHAVIOUR	
Nothing particular	0
Standing or falling down on a roadway	1
Walking along a wrong side of a roadway	2
Enter a roadway at a red signal	3
Imprudent enter a roadway:	
– before a moving vehicle	4
– from behing a vehicle or an obstacle	5
Incorrect crossing a roadway:	
– at unseen places	6
– slowing down or stopping	7
– running across	8
– walking in subgrade (line)	9
– at prohibited places	10
Children up to seven years old:	
– playing in a roadway	11
– running onto a roadway	12
– cycling and so on	13
Falling in/from a vehicle	14
Others	15

A STUDY OF ACCIDENT MECHANISMS ON AN URBAN MOTORWAY

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INTRODUCTION

The Ayalon Highway is a unique motorway in Israel. It crosses the Tel-Aviv metropolis from north to south and connects two main motorways, leading to Haifa and Jerusalem. It carries one of the highest traffic volumes throughout the country -- about 100,000 vehicles daily. Having eight interchanges on about thirteen kilometers of motorway, Ayalon Highway serves as a fast access to any district (industrial zone, business centres, residential areas, university facilities) of greater Tel Aviv. Being heavily travelled most hours of the day, Ayalon Highway is deemed to satisfy a high standard of safety, especially concerning road conditions and traffic arrangements.

In 1996, the Ayalon Highway Authority began applying some tools -- bollards (Hakkert & Gitelman, 1997), which are believed to improve the traffic arrangement at motorway exits. In order to evaluate the potential effect of this treatment and to highlight the needs for other remedial measures, a detailed analysis of accidents occurring on the Ayalon motorway was necessitated.

As had happened with many other accident studies, the data attainable from the Central Bureau of Statistics were unsatisfactory for the study purposes. Except for the date, hour, road number, collision type, number of vehicles involved, and number of injuries, neither the exact location nor the events and manoeuvres prior to the collision could be reconstructed using these data. Hence, in order to supplement the lack of information, we were forced to apply to initial police files. As underlined in Gitelman & Hakkert (1996), it is a widespread phenomenon that a detailed accident investigation is preceded by a significant amount of routine work on searching and careful perusal of police files. Such a situation, on the one hand, deters the conduct of many studies; conversely, the process mostly repeats the work already performed by the police accident examiners.

A feasible solution that can greatly alleviate the situation is to have a computerized accident report containing the vocabulary used by the police investigators, and varying in accordance with the accident type under consideration. Such a tool, on the one hand, can assist the police examiner in the rapid registration of an occurrence; conversely, it would

result in the creation of one multi-aspect information source suitable for safety remedial work. In order to provide the proper information for the tool discussed, a comprehensive accident classification must be developed. Analyzing the Ayalon Highway accidents, we aspired to make the best contribution to the information base mentioned above. The approach used for the accident analysis was intentionally general; applied previously for single-vehicle accident classification (Gitelman & Hakkert, 1996). Its main points are:

- to reconstruct the accident occurrence, all the available information sources, i.e., on-site accident report, the police investigator's conclusions, motorists' evidence, and the judgement, are thoroughly scanned;
- comparing the sample examples, the set of descriptive items that are sufficient to reflect the accident contents, is defined;
- the set introduced above comprises the framework for a computer-fitted description of any accident considered, which is converted later into a database file;
- having the uniform set of database records, different accident characteristics are analyzed, with emphasis on accident mechanism exposure.

ACCIDENT DATA FOR ANALYSIS

The data pertaining to Ayalon motorway accidents were collected from the original police files which are kept in the Tel-Aviv police archives. As it was important to analyze the latest Ayalon accidents, all attainable 1995 files were taken into account, with the addition of accidents occurring during the second half of 1994. The total sample comprised 139 cases. The accident locations were repeatedly verified according to the parties involved and detailed map data.

The structure of the database file for Ayalon accident description is presented in Table 1. This framework is sufficient to keep both the formal accident data (day, time, location, severity), and the details of occurrence: for every vehicle involved, up to three manoeuvres prior-to-the-collision can be noted, in accordance with the manoeuvres of others (see fields A0-A2, B0-B2, C0-C2 in Table 1). The fields REASONS, NOTES, VISIBILITY, ROADCOND are intended to reflect specific factors and circumstances which are relevant to the case, e.g., "traffic jam," "roadworks," "wet road," "limited visibility," etc.

CONSIDERATION OF ACCIDENT CHARACTERISTICS

As detailed accident descriptions are presented in the database file, various types of in-depth analysis can be performed. For the urban motorway accidents considered, the following aspects were examined: accident location (along the motorway and with reference to interchange components); accident patterns; accident severity, and factors characteristic for the sample. All types of consideration were aimed to ascertain as many accident regularities as possible, and to expose accident mechanisms relevant for the group analyzed.

ACCIDENT LOCATIONS

The accident locations along the Ayalon motorway (Figure 1), demonstrate that the three southern interchanges and junctions between them are characterized by an increased number of accidents. While the whole road has an approximately equal accident distribution in the two directions: 52.5% to the north versus 47.5% to the south (the travelling directions are separated by railway tracks), the sites with more accidents tend to have them more to the south, whereas the remainder of sites are to the north (the difference is significant, $\alpha = 0.05$).

In order to identify the accident patterns relevant to different road structures within the motorway considered, the accident locations were classified with reference to interchange components (Figure 2):

ON - accidents that occur on the interchange, including the final part of exit ramps and the beginning of lane drops from the interchange leading to the on-ramp;
UNDER - accidents that occur under the bridge;
EXIT - accidents that occur at the exit ramp area, starting with the deceleration lane;
ENTR - accidents that occur at the entry ramp area;
BTW - accidents that occur at junctions between interchanges, i.e., accidents not belonging to any of the above locations.

Table 2 presents the accident distribution in accordance with their location and type of collision. It can be concluded from Table 2 that the share of accidents occurring at the interchange area (ON, UNDER, EXIT, ENTR) is about the same as between the interchanges: 52% versus 48%; and the majority of interchange-area accidents (69%) have EXIT and ON locations (whereas about half --46% -- of ON accidents occur at the top of exit ramps). The leading collision type everywhere is "rear-end" (50% of cases, on average); other dominant collision types are "side-side" (UNDER), "rear-side" (ON), "rear-side" (EXIT), and single-vehicle accidents (BTW).

ACCIDENT PATTERNS

In order to decide how to treat the phenomenon, it is first necessary to learn its mechanism. Therefore, it was of principal importance to point out accident patterns (mainly, vehicle manoeuvres prior to a collision) which characterize the Ayalon Highway accidents. With this in mind, the accident stories at five areas defined above were considered in detail. For example, the 26 EXIT area accidents included 6 cases with direct gore area involvement (i.e., one of the prior-to-a-collision manoeuvres was a gore area crossing); 15 cases with exit ramp involvement (i.e., one or both the vehicles were leaving or entering exit ramps while the accident occurred); 5 cases took place in the mainstream. Table 3 summarizes this consideration in general and demonstrates that accident pattern distribution changes insignificantly from area to area ($\chi^2_{16} = 24.19$). The most widespread patterns are:

- Vehicles, being in the same lane, do not keep a distance and collide "rear-end" (36.7% of all the cases, 27% in EXIT area);

- An accident occurs while one of the vehicles is changing lane (21.6% of the whole sample; 35.6% of EXIT accidents).

The full list of accident patterns for the Ayalon motorway during the period considered includes:

A- a late-coming attempt to exit the motorway (with sharp right-manoeuvre, crossing gore-area), 6 cases;
B- a late-coming attempt to return to or an early-coming attempt to enter the motorway (with sharp left-manoeuvre through the gore-area), 2 cases;
C- a single-vehicle accident (loss of control), 21 cases;
D- a deviation from a carriageway without intending to change a lane, 22 cases;
E- one vehicle collides with another while they are moving in a platoon, 51 cases;
F- a collision while changing a lane, 22 cases;
G- a pedestrian crossing the vehicle carriageway, 3 cases;
H- an opened door hits a motorcycle, 2 cases;
I- a collision at a junction with traffic lights (ON-area), the vehicles coming from different directions, 6 cases;
J- a passenger falling when a vehicle is in motion after stopping on a shoulder; 1 case;
K- a load falling from a moving vehicle, and hitting the following vehicle, 3 cases.

In order to select patterns that merit treatment as characteristic, an approach proposed by Heydecker & Wu (1991) was applied. They developed a technique for the identification of a typical subset feature when the common behaviour of the feature in the whole set is known. In a simplified version, one can manipulate the frequency of the feature in the subset and the evaluated median for the entire set. If the first value exceeds the second, the feature is considered to be specific for the subset discussed. Having used the number of cases for the accident patterns of Ayalon Highway as a feature considered, the median value for the whole sample was derived: it lies between 3 and 6, closer to 3. Consequently, from the above eleven accident patterns, six (A, C, D, E, F, I) were found to be characteristic for the urban motorway considered.

ACCIDENT SEVERITY

The severity rate of Ayalon motorway accidents is very low: there is only one fatal accident (single-vehicle) in the whole set, which occurred between the interchanges; 92% of the accidents are with slight injuries. In this regard, no difference was found between the areas ($\chi^2_8 = 3.55$) and between the collision types ($\chi^2_6 = 10.93$). However, the share of accidents with a high number of injuries (3+) is above the average in ON and EXIT areas. A higher number of injuries was observed in "rear-end" accidents in comparison with other types of collision: 25.7% with two injuries (the average is 20.9%), 22.8% with three or more (the average is 14.4%). This difference is confirmed statistically ($\alpha = 0.05$) and quite anticipated because one third (34%) of "rear-end" accidents are "chain"- accidents (more than two vehicles involved).

TRAFFIC FACTORS

Two factors were found to be characteristic for the Ayalon Highway accidents: "roadworks" and "traffic jams." While the "roadworks" factor appears uniformly through all the areas (8.6% of the cases), the "traffic jam" influence changes from area to area: 11% involvement in ON and ENTR accidents; 36% involvement in the remaining areas ($\alpha > 0.30$). The strongest influence of the "traffic jam" factor was observed in the EXIT area: in about half (46%) of the accidents, the vehicles moved in a jam.

The majority of accidents with "traffic jam" factor were of "rear-end" (71%) or "rear-side" (27%) type.

AN EXAMPLE: THE POTENTIAL FOR BOLLARD APPLICATION AT EXIT AREAS

Bollards are plastic post delineators which emphasize the gore area location at motorway exits (Hakkert & Gitelman, 1997). The tools are called to contribute to better arrangement of the traffic streams at motorway exit points, and reduce erratic vehicle manoeuvres at these areas. According to the purpose defined, the following summary of the Ayalon accidents promises a potential benefit of bollard application at the motorway gore areas:

- The erratic manoeuvre of exit gore area crossing appears in six accidents (23% of EXIT area cases; 4.3% of the whole set);

- The erratic manoeuvre of gore area crossing through all the interchange areas (EXIT, ENTR, ON) appears in nine cases - 6.5% of the whole set;

- The direct and indirect influence of the gore area, i.e., the situation where gore area emphasizing could help to avoid an erratic manoeuvre, is relevant to fifteen accidents (10.8% of the cases, including all the areas considered).

CONCLUSIONS

In this study, we sought to perform an in-depth consideration of accidents occurring on the Ayalon Highway -- an urban motorway in Israel. Based on a sample of 139 most recent accidents, the motorway accident location and severity profiles were analyzed, and the dominant accident patterns, including collision types, vehicle manoeuvres prior-to-a-collision, and factors essential for the occurrences, were pointed out.

The method of data presentation (in particular, the developed computer-fitted form of accident description) and analysis was aimed to provide the best contribution to a comprehensive accident classification -- the information basis of computerized accident reporting. The latter presents a tool that is needed, on the one hand, to facilitate the regular work on accident registration performed by the police, and, conversely, to provide a satisfactory background for various crash investigations.

The results helped to reach a conclusion concerning the potential efficiency of bollard application at exit gore areas of the Ayalon motorway. Combining the results of accident analysis with experimental field observations and literature review, the bollard treatment was finally recommended for application on the Ayalon Highway (Hakkert & Gitelman, 1997).

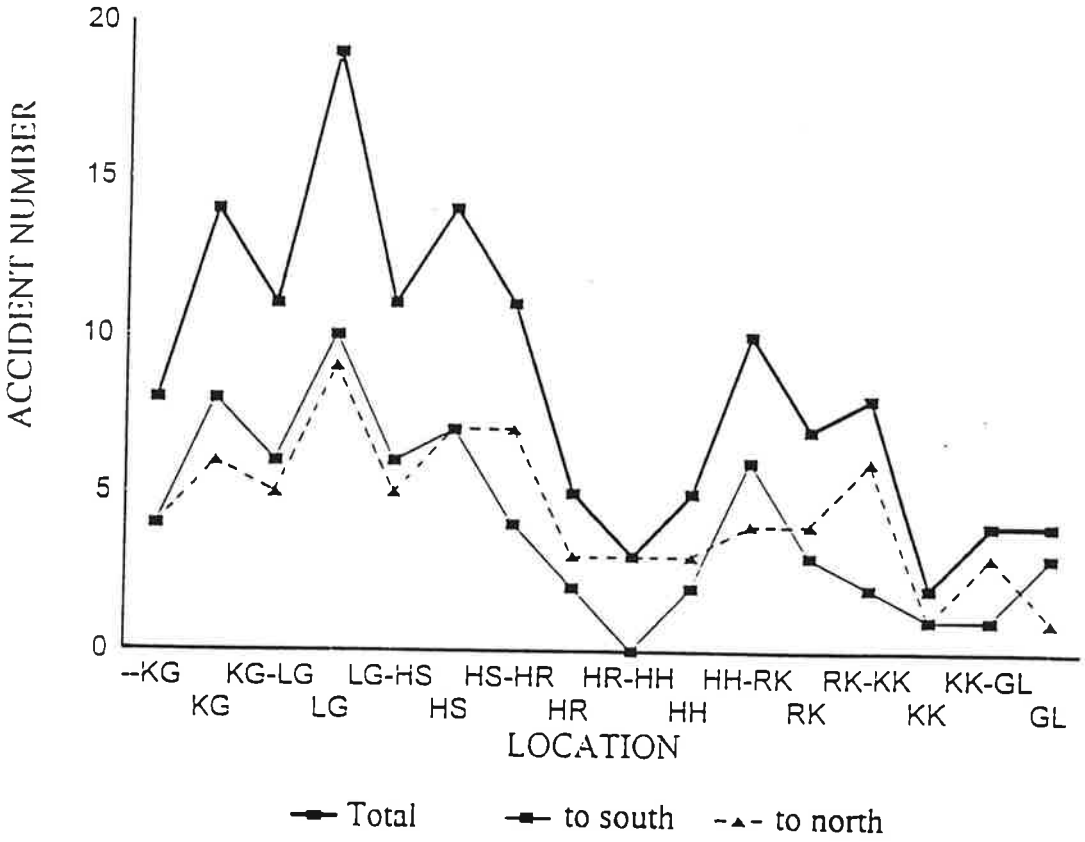
A large proportion of accidents analyzed occurred between interchanges where a part of them are single-vehicle accidents; another includes rear-end collisions, and a third involves lane-changes. The Ayalon Highway Authority is in the process of installing a real-time traffic control and surveillance system. This will include real-time traffic monitoring and communication with drivers through Lane Control Signs and Variable Message Signs. It is believed that such interaction can be utilized to reduce the number of accidents of the types mentioned above.

REFERENCES

1. Gitelman, V. & Hakkert, A.S. "The Construction of Accident Patterns from Police Accident Records." Proceedings of the "Road Safety in Europe" Conference, Birmingham, U.K., 1996, No. 7A, Part 2, pp. 203-220.

2. Hakkert, A.S. & Gitelman, V. "A Study of the Efficiency of Bollards at Exit Gore Areas." To be presented at the "Traffic Safety on Two Continents" Conference, Lisbon, Portugal, 22-24 September, 1997.

3. Heydecker, B.G. & Wu, J. "Using the Information in Road Accident Records." Proceedings of Seminar K of the Summer Annual Meeting of PTRC (European Transport Highways & Planning), University of Sussex, U.K., P350, 1991, pp. 241-255.



Interchanges: KG - Kibutz Galuiot; LG - Lagardia; HS - Hashalom; HR - Harakevet; HH - Hahalaha; RK - Rokach; KK - Keren Hakayemet; GL - Glilot; the remainder of locations are intermediate junctions.

Figure 1. Ayalon Accident Location along the Motorway: Grouped for Interchanges and Intermediate Junctions.

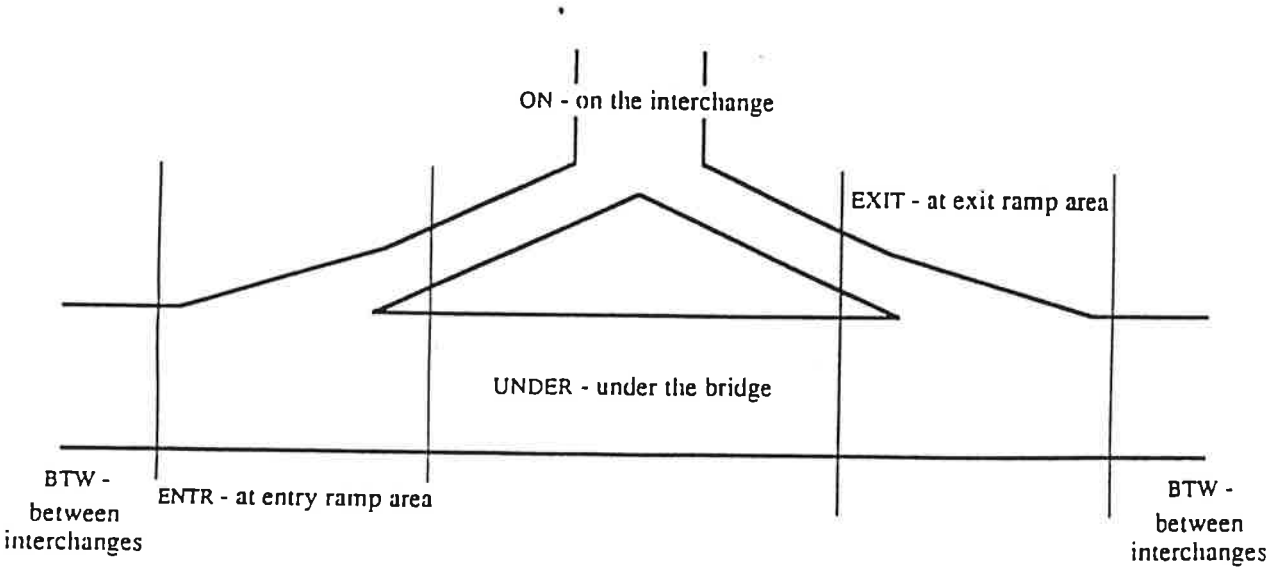


Figure 2. Motorway Accident Location with Reference to Interchange Components.

Table 1. Database File Structure For Ayalon Motorway Accident Description

Field Name	Description	Characteristics	Example* *(comments)*
POLICE FILE	Police file number	Original	4622
DATE	Accident date	Original	17.07
YEAR	Accident year	95 or 94	95
HOUR	Accident hour	Original	23:00
DIRECTION	Travelling direction	North or South	N *(north)*
INTERCHANGE	Interchange name	One of eight	KK *(Keren Hakayemet)*
LOCATION	Accident location	Before/After interchange; Exit ramp; Gore area; etc.	Gore Area, ER to ICh *(gore area & exit ramp involved)*
VEHNUMBER	Number of vehicles involved	1, 2, 3+	2
ACCTYPE	Accident type	Rear-end/ Rear-side/ Multiple rear-end/ etc.	Rear-end? *(apparently, rear-end type)*
A-VEHICLE	Type of vehicle **A**	Private/ Light goods/ Truck/ Motorcycle	Pr *(private)*
B-VEHICLE	Type of vehicle **B**	See above	Pr *(private)*
C-VEHICLE	Type of vehicle **C**	See above	--
A0 A1 A2	Manoeuvres of vehicle **A**	Chain of vehicle movements prior to the collision, by short sentences	right lane dev.right, crossed gore area hit **B**
B0 B1 B2	Manoeuvres of vehicle **B**	See above	ER, before **A** ER, left lane was hit by **A** behind
C0 C1 C2	Manoeuvres of vehicle **C**	See above	-- -- --
REASONS	Reasons for the manoeuvres performed	Incl. traffic conditions & drives' explanations, according to manoeuvres, by short sentences	**A1**-late to turn right; **A2**:"B was stopping" *("" mean driver's version)*
NOTES	Remarks about the occurrence & drivers involved	Incl. general road or traffic conditions & previous offenses of guilty party	**A** has 24 prevoffenses in 1969-1992
LANES	Number of lanes	2,3,4 (from the police file)	3
VISIBILITY	Visibility conditions	If a deficiency is noticed in the police file, e.g., night-lit, lighting failed,etc.	--
ROADCOND	Road conditions	If special weather or road conditions are noticed, e.g., wet, slippery, left curve, etc.	--
KILLED	Number of fatalities	A number	0
SERINJ	Number of serious injuries	A number	0
SLINJ	Number of slight injuries	A number	2
TO_BLAME	Guilty party	According to judgement	**A**-sigh violation

*The case: Vehicle **A** was on the right lane of the motorway, before the exit to KK-interchange, when it sharply deviated right to the exit through the gore area, and hit from behind vehicle **B** that was going on the left lane of exit ramps up to the interchange.

Table 2. Ayalon Motorway Accident Distribution in Accordance with Their Location and Type of Collision

Accident Location with Reference to Interchange	Type of Collision						Total
	Single-Vehicle Accident	Side-Side	Rear-Side	Rear-End	With a Pedestrian	With Load Dropped	
UNDER	2	4 40%	--	4 40%	--	--	10 *14%[a]*
ON	1	1	9 37%	13 54%	--	--	24 *33.8%[a]*
EXIT	5	1	9 36%	9 36%	1	--	25 *35.2%[a]*
ENTR	1	1	2	8 67%	--	--	12 *17%[a]*
BTW	13	9	5	35 52%	2	3	67
Total	22 17.4%	16	25 18.1%	69 50%	3	3	138

[a]Division of interchange-area accidents.
The rest of percentages illustrate the dominant collision types for specific locations.

Table 3. Ayalon Motorway Accident Distribution According to Accident Location and Vehicles' Manoeuvres Prior-to-a-Collision

Accident Location with Reference to Interchange	Vehicles' Manoeuvres Prior-to-a-Collision					Total
	Single Vehicle, Loss of Control	Two Vehicles Moving the Same Direction			Others[a]	
		Changing a Lane	Parallel Lanes, Non-Intended Deviation	The Same Lane, Not Keeping Distance		
UNDER	1	1	3	4	1	10
ON	1	2	2	13	6	24
EXIT	5	9	4	7	1	26
ENTR	1	5	2	4	--	12
BTW	13	13	13	23	5	67
Total	21	30	24	51	13	139

[a] Others: with a pedestrian; a passenger falling from the vehicle; a load falling from the vehicle; joining on-interchange traffic flows.

Headways, collisions and traffic : some results on French motorways and towards new questions

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1 Introduction

In France, the rear-end or multiple collisions represent 14% of the injury accidents and when considering only the accidents on motorways, this part reaches 40%. There is a lack of "epidemiological" knowledge about the occurrence of such rear-end collisions, even if statistical correlations have been highlighted and suggest the contribution of factors such as speed, drowsiness, visibility or weather conditions. Concurrently there is a lack of traffic control strategies to cope with these collisions, the few experiments based on Variable Message Signs (VMS) do not lead to a sufficient basis of statements. In France for instance the efficiency of these VMS on driver's speeds have been assessed (Hajsalem, 1988; Aron 1994) but due to the size of the experiments and the infrequency of accidents, no effect on accidents could be reported.

The stakes in terms of injury accidents, and the attempt at finding new ways to inform drivers made it worthy to investigate the incidence of car following phenomena and headway-related crashes. A recent series of studies, funded by DSCR[1] and ASFA[2], conducted on French motorways were aimed to develop our knowledge about the link between short headways and traffic safety on motorways. Inrets involved in this movement, tried to analyse the incidence of headways in relation to traffic and its relationships with speeding and risk (Aron et al, 1997). The final goal of those in charge of traffic safety on motorways is to find, through the results, appropriate and well targeted messages to reduce injuries on motorways. This paper sets out to raise, on the basis of some findings, some questions to make advances in this area.

2 Method and Data

The system of interactions between traffic, time headways and accidents is a complex one : the level of *traffic flow* influences the time headway; the traffic flow itself and its composition (cars/trucks) depends on the *time dimension* (hour of day); the time dimension is also linked with the mobility of drivers (type of journey) and their behavioural tendencies (alcohol or speed, for instance). To study the relationships, we need data covering the three areas *accidents*, *traffic flow* and *time headways* on the *same network* and during the *same time*. Such a complete set of data does not exist. Our research is an attempt to explore the relationships through existing data collected for other purposes, all in 1994.

2-1 The method

The method to explore the relationships uses three sources of data :

- the national accident file for 1994, providing information on rear-end collisions,

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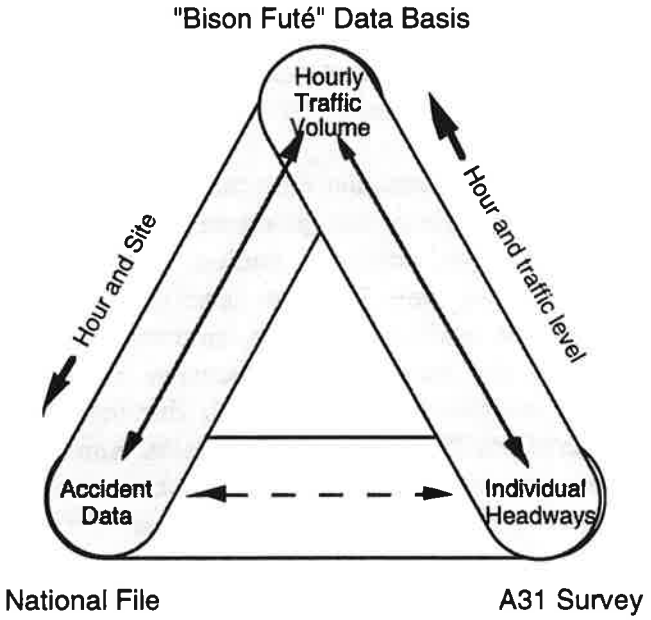
[1] DSCR: Direction de la Sécurité et de la Circulation Routières (Department of Road Safety at the french Ministery of Transport)

[2] ASFA : Association des Sociétés Françaises d'Autoroute (Association of French Motorway Companies)

- the file "Bison Futé" for 1994, providing the hourly traffic volumes on the basis of a number of traffic counting stations,
- and a sample of headways surveyed during a hundred-day period in 1994 on the french motorway A31.

Our approach is founded on one main assertion : on motorways, the level of traffic volume is the first common variable descriptive of traffic, time headways and yearly accidents distributions over space and time. The second strong idea, an hypothesis to be verified[3], is that the link between traffic and time headways, once the traffic level is fixed, does not depend so much on the location on the motorway. Starting from these views, the link is assessed through two intermediate variables, the traffic volume and the time of the day. Figure 1 shows a diagram representing the potential of exploring links between accidents, traffic and headways, on the basis of the available data.

Figure 1. Linking data on accidents, traffic and headways



2-2 The Data

All the data were collected during the year 1994.

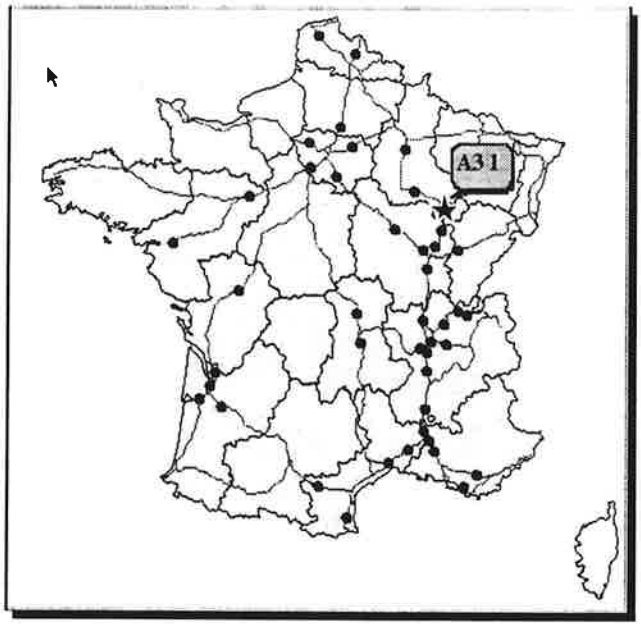
The traffic

A lot of measurement points exist on the French interurban motorways. Among them, a system of 44 traffic count stations form a permanent data file used by "Bison Futé" for the traffic prediction and are easily available. They give, all along the year, in each sense, the hourly volume of traffic and the hourly average speed. We used in the study the 1994 database : only counts from 41 stations were available for 1994. Each station gives the exact traffic volume of the section comprised between the upstream and the downstream intersections ; the sections attached to the Bison Futé system have a total length of 795 km, which is 16% of the total 5,000 km motorway network. If we consider traffic flow and accident patterns by hour this data base proves to be representative of the whole network (Aron et al, 1996).

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[3] Further data are currently beeing collected by ASFA (from autumn1997) and will allow this verification.

Figure 2. Location of the Bison Futé measurement stations on motorways



The accident data on French motorways

The injury accidents are recorded in the French National Accident Database. For each accident, all the usual data concerning the road site, the driver and the vehicle are stored. In this study, we have processed only the type of the accident, its hour and its location (motorway, kilometre point). Only interurban motorways *rear-end and multiple collisions* have been considered: 1460 occurred in 1994, which represents 43 % of the motorway accidents. We checked in (Aron et al, 1996) that the distributions of accidents versus various criteria (the hour in the day, the month in the year, the percentage of rear-end collisions out of all accidents) are quite the same when considering the whole set of motorway accidents or only the accidents occurring on "Bison Futé" sections (210 accidents). We choose to work on this last sample of 210 rear end and multiple collisions to match traffic and accident data.

The headways (time headways)

The French motorway company SAPRR[4], responsible for a number of motorways in France, has extensively studied the impact of Variable Message Signs on a 25 kilometres section of the two-lanes motorway A31, near the town Dijon. These VMS displayed a speed limit message either during bad weather conditions or when the traffic flow is high. For the evaluation of these VMS, were processed two sets of data : one reference set, where the VMS were switched off, and a second set, where the VMS were activated. The first set includes 433 000 vehicles for which headways and speeds have been recorded. In this paper the term *headway* is used for *time headway* defined as the length of time separating the time of passage of the rear end of the vehicle and the front of the following vehicle [5]..

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[4] Société des Autoroutes Paris Rhin Rhône

[5] Unless the contrary is specified, the presented headways address the car drivers, or more precisely the vehicles the length of which is less than 7.5 m.

3 Results

To analyse the information collected in the three areas (*accidents*, *traffic flow* and *time headways*) we use, as mentioned in part 2, two intermediate criteria : the level of traffic flow per hour, and as time category the 24 hours in the day. The level of traffic flow per hour is a *flow two lanes* .

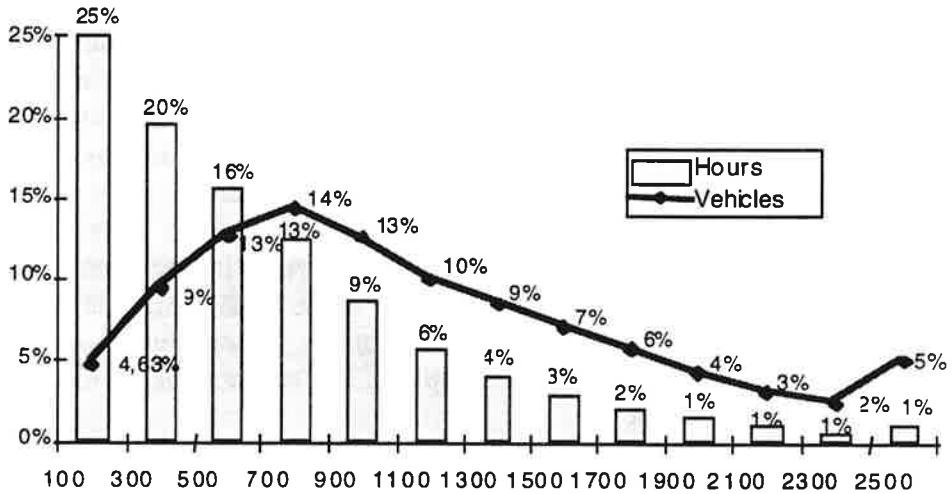
The traffic volume in number of vehicles is computed *by lane* (the total volume divided by the number of the lanes) and adjusted for two lanes. The flow by lane ranges from 100 to 1200 vehicles/lane /hour. Thirteen classes of traffic volume two lanes are defined [6].: 0-200, 200-400, 400-600, 600-800, 800-1000, 1000-1200, 1200-1400, 1400-1600,1600-2000, 2000-2200, 2200-2400, >2400.

3-1 Accidents and traffic on motorways

Traffic flow distribution (by traffic level class)

The Figure 3 shows the frequency of the hours in the year and the frequency of the observed vehicles in relation to the flow level two lanes.

Figure 3. Frequency of the hours in the year and frequency of the observed vehicles in relation to the flow level



The lowest class (0-200 vehicles /two lanes) is observed during 25% of the hours in the year (i.e. 2200 hours out of the 8760 hours of the year); this accounts for 5% of the vehicles (the total traffic flow)[7]. On interurban motorways heavy traffic levels are relatively infrequent. In other words the congestion problems are concentrated on a limited number of hours in a year.

Accidents and traffic (by time category)

The type of accidents investigated are rear-end and multiple collisions. The following figure (Figure 4) gives the number of accidents in relation to the hour in the day. In addition to this distribution, we have computed and superposed on the same figure the evolution of

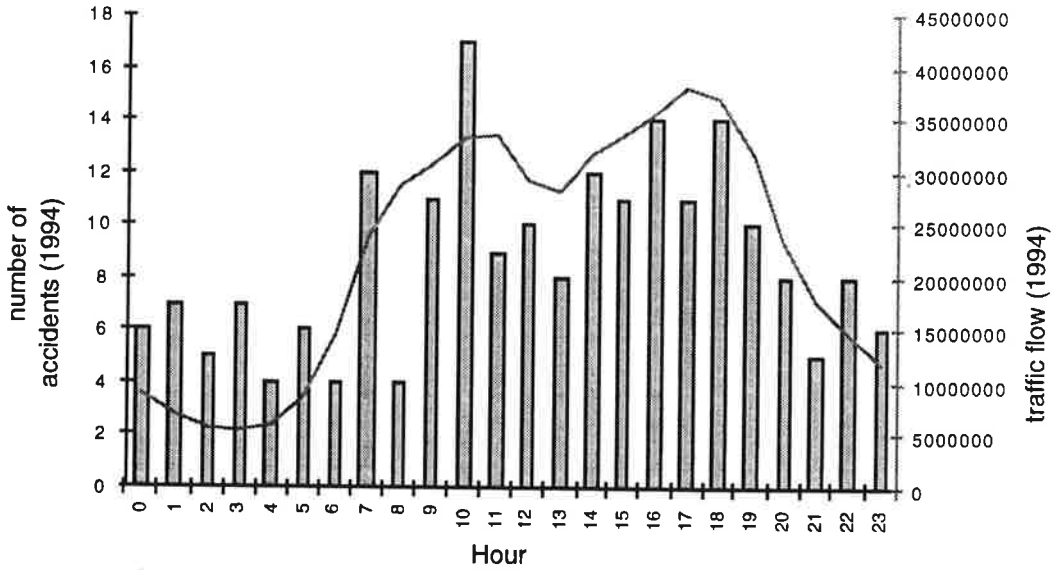
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[6] The maximum flow per lane reaches 1800 vehicles, but is rarely observed on the interurban motorways, and the flows greater than 1200 vehicles / hour (one vehicle every three seconds) have been grouped

[7] This means that in this class, the traffic volume per hour is five times less than the average.

the total traffic flow along the day, in order to visualise the hours where the rate of accidents is important.

Figure 4. Frequency of the accidents and average traffic flow in relation to the hour in the day



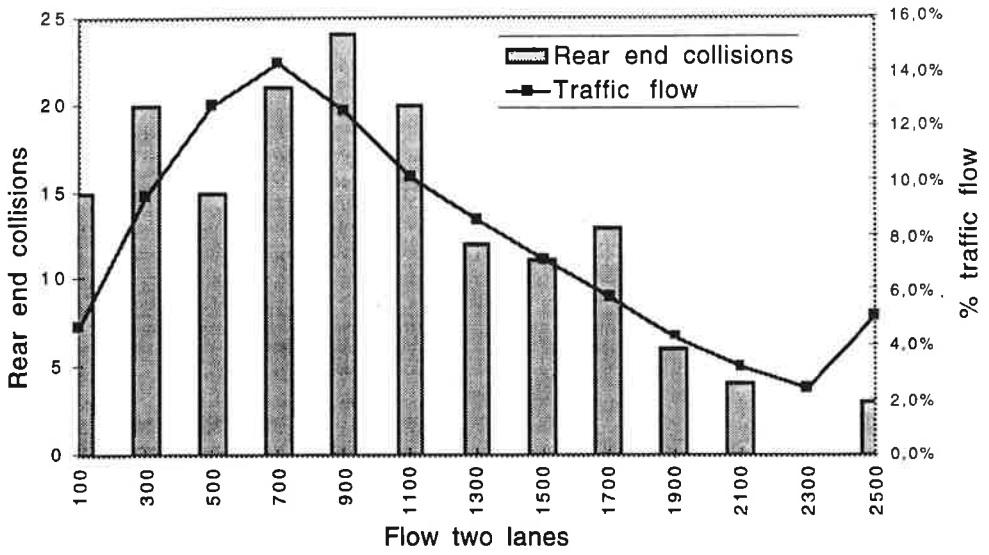
The rate of rear-end collisions, defined as the number of accidents divided by the flow, is higher at the hours where the number of accidents is higher than the curve of average traffic flow. The accident rates are high mainly at night-time (22-6 a m). This implies to process separately daytime and night-time in further analysis, because the most likely cause of these accidents are probably not of the same nature.

Accidents and traffic (by traffic level category)

The traffic flow, at the very moment of the accident, is not known; only the hourly traffic volume is available from a Bison Futé section *if* the accident took place on such a section. Figure 5 presents the matched data (accidents and traffic) from the « Bison futé »system.

A large part of rear-end collisions (70%) occur at low or medium traffic levels (less than 1200 vehicles /hour/two lanes); 21% of rear collisions occur at very low traffic level (less than 400 vehicles/hour/ two lanes). Further risk calculations are available from (Aron, 1997) that raise important methodological points. They show, or strongly suggest, that the higher risks occur at these *low traffic levels*, especially at night (1-6 a m). For more significant results at high traffic levels the risk analysis could be improved in at least three directions: processing more years, processing damage incidents, processing more roads.

Figure 5. Accidents and traffic flow in relation to the traffic flow level



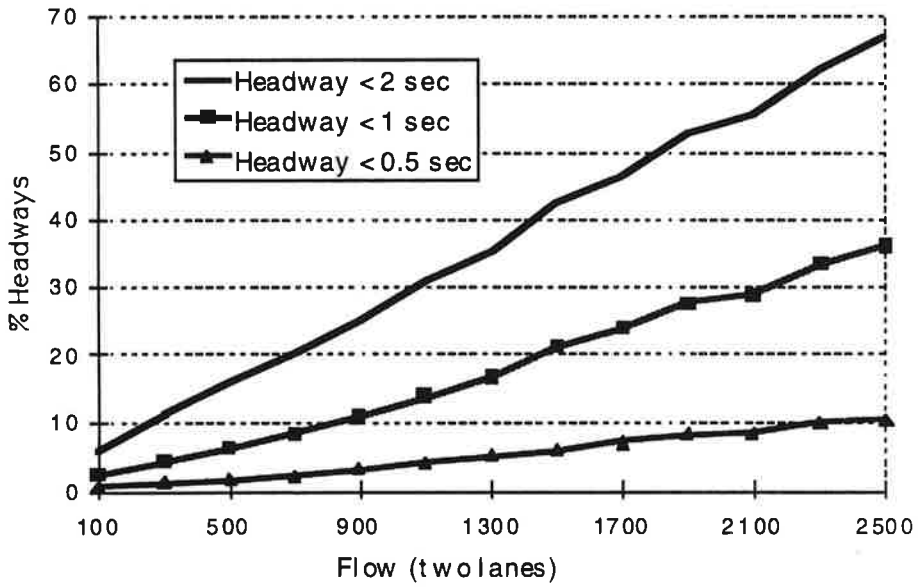
3-2 Headways and traffic on motorways

The overall occurrence of short headways (less than two seconds) has been computed for each traffic category (the classes of traffic volume) and then the role of specific factors (sequence of vehicles, time category, lane) is emphasised .

Influence of the traffic level on the headways

The definition of the "short" headways is miscellaneous; the evolution of the percentage in relation to the traffic, as shown on Figure 6, seems different with the different thresholds studied : 2s, 1s and 0,5s.

Figure 6. The influence of traffic flow level on cars headways less than 0.5 second, 1 second, 2 seconds



The examination of this figure leads to the following remarks :

1. The evolution is quite linear, but the slopes are very different :
- for the threshold of 2 seconds, when the flow ranges from 300 to 2500 veh /h, the percentage of short headways raises from 11% to 67%.
- if the threshold is 1 second, it raises from 4% to 36% (the slope is the half of the precedent)
- if the threshold is 0,5 second, it raises from around 0% to around 10 %

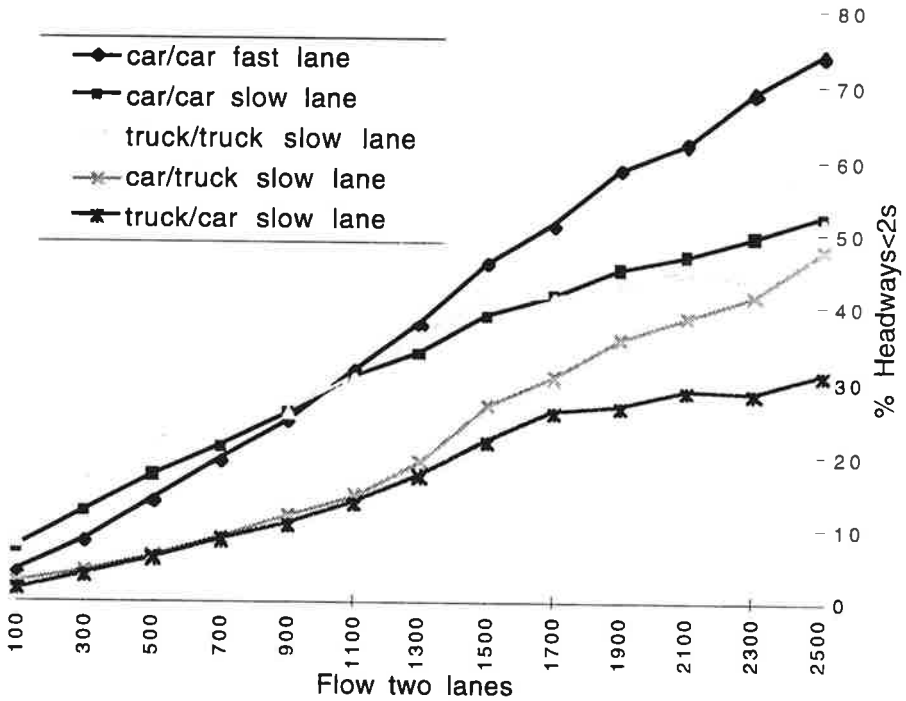
We can assume that a part of the evolution is due to the traffic level, and, a part to the behaviour of "aggressive" or "competitive" drivers whose number does not increases proportionately to the traffic, but represents the "hard core" of car following (or overtaking) drivers.

2. Even at very light flows (300 vehicles/hour for the two lanes), 11% of the headways are smaller than 2 seconds, although the average headway is theoretically in this class 24 seconds (3600 s/150 veh/h/lane). This percentage of headways less than 2 seconds, around 10% at low traffic levels can be linked with the high rate of rear end collisions by very light traffic, especially at night.

Influence of the lane and types of vehicles on the headways

Besides the level of the traffic, the influence of a number of factors on the percentage of small headways has been computed: the most important factors prove to be *the lane* and the sequence of successive vehicles (Figure 7). It is worthy to note that headways, at the same level of traffic flow by lane, are not correlated with the time of the day. The light rain seems also to have a very small influence on the headways (Aron et al, 1996 or 1997).

Figure 7. The Influence of the type of lane on headways less than 2 seconds with the distinction of successive cars



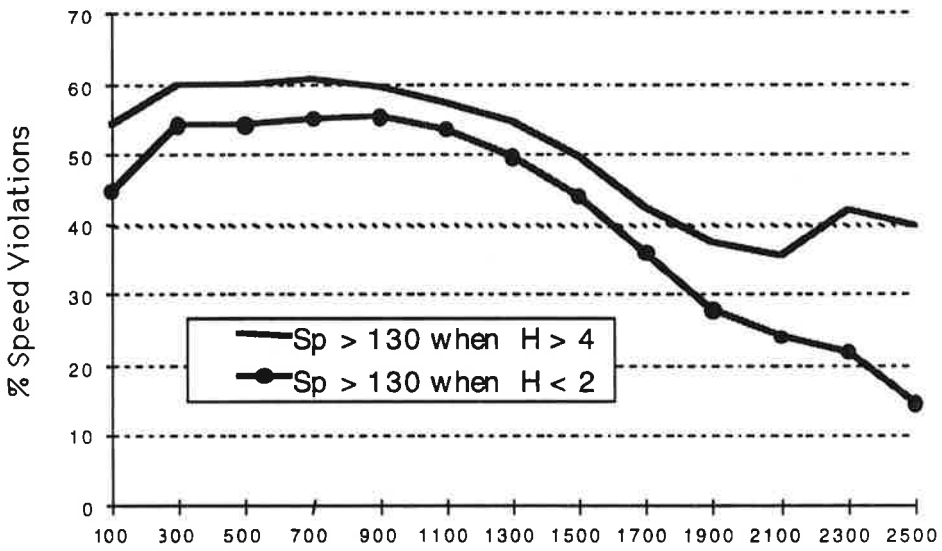
The headways are more frequently shorter (<2s) on the fast lane, over the traffic level of 1000 veh/two lanes; even at low traffic levels where there is much more vehicles on the

slow lane [8] the incidence of short headways on the fast lane is significant. On the slow lane, in France, there are platoons of trucks, they drive very closely each other (as close as a car following a car).The headway is greater only *when a truck follows a car,* probably because, in this case, the car has a greater speed and is moving forward. By consequence the observed percentage of short headways truck/car is smaller.

3-3 Speeding violations and Short headways on motorways

We compare now the tendency to drive over the legal limit (>130 km/h) with short headways (<2s) and the same tendency in more free traffic (headways >4s). We can see on figure 8 the evolution of the percentage of speeds over 130 km/h with headways <2s in relation to the traffic level.

Figure 8. High speeds and headways (cars only)



This percentage stands between 50% and 60% for low and medium traffic levels (under 1200 veh/ two lanes) and then declines steadily for higher traffic levels (20% over 2200 veh/two lanes); it remains still 15% above the 2400 level. So, for a large range of traffic levels (most part of the time on motorways as assessed by the traffic distribution of Figure 3) illegal speeds and short headways goes hand in hand. The same patterns appear with curves dealing with speeds over 140 km/h or 150 km/h[9] .This confirm the unsafe character of short headways.

It appears also that in some extent (until 1800 veh /h/ two lanes) the speeding tendency is of the same order in traffic flow with (the curve <2s) or without short headways (> 4s) as if the speeding behaviour tendency were not influenced by traffic environment. Note that there are few cases where, at the same time, the traffic is high (2500 vehicles for two lanes) and the headway more than 4 seconds, so, for this traffic class, the increase of the percentage of drivers over the speed limit is not significant.

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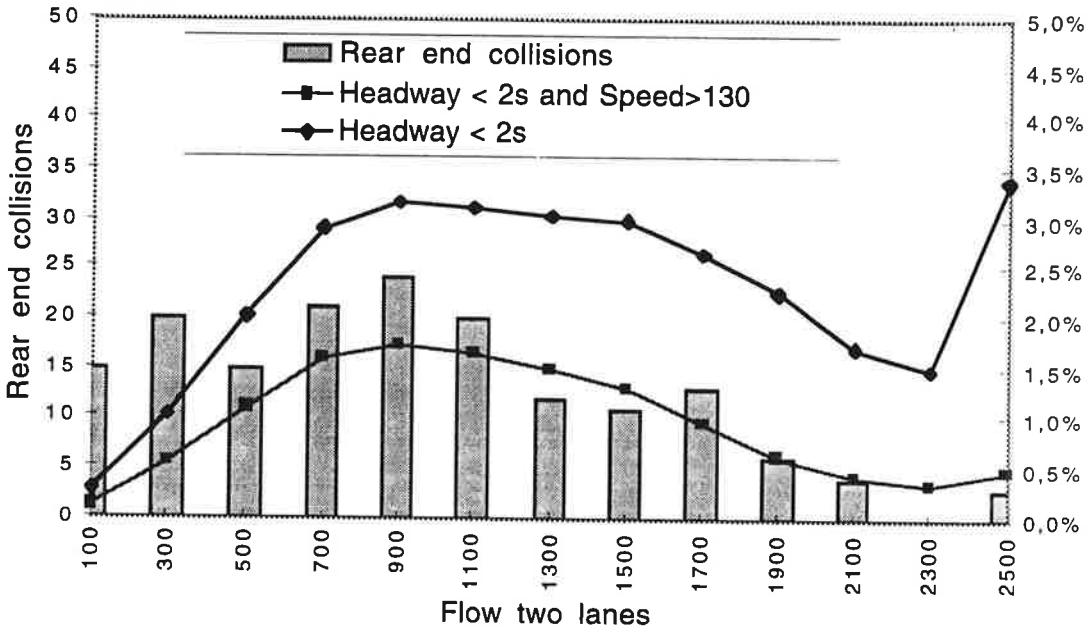
[8] (80% when the flow per lane is less than 300 vehicles)

[9] The figures are given in the Lisbonne paper (Aron et al , 1997)

3-4 Speed sand headways : a risk factor

The final figure stresses the stakes in terms of the total traffic flows involved. The rear-end collisions, the incidence of vehicles with short headways (<2s) are plotted on the same figure (Figure 9). It results of the calculation in each traffic class of the following ratio : number of vehicles with headway<2s in the class / total number of vehicles. In addition we plot the curve of occurrence of short headways with illegal speeds[10].

Figure 9. Occurrence of short headways and Accident frequencies :



The incidence of traffic flow with illegal speeds together with short headways appear to be the higher at levels of traffic between 400 and 1200 veh/two lanes. Taking in mind that this range of traffic levels on motorways account for 50 % of the accidents in a year, the short headways with high speeds can be assumed to be a major risk factor on motorways.

Conclusion

This investigation contributes to improve the epidemiological knowledge on short time headways in relation to traffic, and highlights their links with rear end collisions. It sets out that short headways less than two seconds often go hand in hand with violations of speed limits. The corresponding safety stakes are constituted by drivers travelling at medium traffic levels. New results assessed with the very short headways, under the threshold of one second, will be useful to complete these findings.

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[10] Resulting from the following ratio : number of vehicles with headway<2s and speed>130km/h in the class divided by the total number of vehicles

References

Aron M. (1997). Headways, rear-end collisions and traffic: the case of french motorways. In *Traffic Safety on two Continents, Conference* Lisbonne *preprint* 24 september 1997.

Aron M., Peytavin J.F., Biecheler M.B.(1996). *Interdistances, trafic et sécurité de la route*. Rapport de convention DSCR/Inrets DERA/MAIA , décembre 1996, 80 p.

Aron M., Peytavin J.F., Biecheler M.B.(1997). Observatoire des vitesses et interdistances sur autoroutes. Contrat ASFA/Inrets. Rapport MAIA/DERA n°9701, fevrier 1997, 39p.

Aron M., Seddiki E. (1994). Using individual measurement of traffic on motorways in Proc of the First World Congress on ATT, Paris, 1994.

Bison Futé, guide méthodologique , Ministère des Transports Décembre 1995.

Hajsalem, H.; Diep, D.; Lassarre,S.(1988). Ie système d'alerte "augmentez vos distances", Inrets Report n° 70, July 1988

The determination of the total number of hospitalized traffic victims by comparison of police and hospital reports.

Peter Polak and Siem Oppe
SWOV, September 1997.

1. Introduction.

This paper is completely based on research carried out by Dr. P.H. Polak, as reported in the SWOV-report R-97-15: Registratiegraad van in ziekenhuizen opgenomen verkeersslachtoffers (in Dutch only).
This paper describes only the methods used and the technical outcomes. Results regarding the implications of the outcomes in terms of safety effects, the representativity of national safety statistics and the extent of under-reporting will be reported separately.

In the Netherlands, as in many other countries, the number of fatalities is well known, but the number of hospitalized road traffic victims is not. A recent estimate of the degree of completeness of the police reporting for this group in the Netherlands is 60%.
In order to check this global indication, a comparison has been made between the records in two well-established databanks: the AVV/BG- databank of police-reported traffic victims, which is the official Dutch database for traffic accidents, and the SIG-databank, which is a database from the Ministry of Health. The first one covers only road traffic victims, but more than hospitalized ones (our target group), the second covers only hospitalized patients, but more than road traffic victims. The first one is incomplete, the second (almost) complete. However, it is not possible to earmark all traffic victims in the second database. Therefore, a study has been carried out, aiming at the following four subgroups of our target group:
the hospitalized road traffic victims that are reported in both databanks, the remaining victims in each databank that belong to the target group and those victims that are missing in both databanks. The possibilities are given in Table 1.

Hospitalized victims	In SIG-database	Not in SIG-database	No target population
In AVV/BG-database	In both databases	only in AVV/BG-database	Not hospitalized
Not in AVV/BG-database	Only in SIG-database	Not in one of the two databases	
No target population	No traffic accident		

Table 1. *Distribution of hospitalized victims, according to presence in databases and belonging to the target population.*

To make this classification, records of victims in both databanks have to be matched on a record by record base. This asks for a unique characteristic that is present in both databanks. In some situations this can be done directly. E.g. in Denmark a personal ID-number is registered in comparable databanks. In the Netherlands such a key-number is not recorded. Matching is therefore based on a (small) number of key-variables that have been registered in both databanks. These key-variables as such are not unique, but it is assumed that the combination (almost always) is. Because there are errors in both databanks, matching is not easy. Therefore, a distance has been defined between records on the basis of the selected matching-keys. If all key-values agree completely, the distance between the records is zero. If some values differ, than the distance is larger than zero; the larger the disagreement, the larger the distance. Distances are computed for all records from the first database with all records in the second database.
Two values are used for the matching process: the distance and a measure of selectivity. If a pair of two records has a certain distance and each of the two records has a considerably higher distance to all records in the other database, than the selectivity for that pair of records is high. Using this matching strategy, matched records can be graded, according to their probability of correctness.
The total number of matches for the two databases was estimated from the matched pairs, using the probability of correct matching. Together with information from the other subgroups of Table 1. an estimate has been computed, not only for the amount of under-reporting of hospitalized road traffic victims in total, but also of the amount of bias regarding factors such as travel mode and region. It was shown that this bias was in some cases substantial and should lead to corrected statistics.

2. Definitions.

As said before, the major aim was to estimate the total number of hospitalized traffic victims. A secondary aim was, to combine the information from both databanks, in order to answer questions that could not be answered on the basis of the separate databanks. The AVV-BG databank has only scarce information about the injuries, while the SIG-databank has only scarce information about the accident. Both aims lead to different matching criteria. For the first aim completeness of the matched outcome set is important, while for the second aim unbiasedness is is of special interest. If the set of matched records is biased, at least information about the extent of it with regard to the most important variables is necessary. The quality of matching is therefore an important characteristic next to the estimated total number of victims.

In order to define a unique key for matching, the following four characteristics have been

used:

- date of birth
- sex
- time and date of accident resp. hospitalization
- hospital

In previous research this combination turned out to be a good basis for matching. Direct matching on the basis of this information is not optimal, because of registration imprecision or errors and uncertainty about the time between the accident and hospitalization. Furthermore, some data is missing.

Not all inconsistencies, deletions or errors have the same importance. E.g., the number of response classes of a variable (two in case of sex, several in case of the hospital), the ease of registration and registration- and checking procedures play a role. Therefore, a weighted measure of discrepancy between the information on the key-variables in both sets is to be recommended. In many areas of research, e.g. in psychology, distance models are used to describe similarities and dissimilarities between sets of characteristics. Objects (persons, opinions on political parties, preferences for consumer goods etc.) and their relations are represented by points in a (multidimensional) space. If two objects are more similar to each other than two other objects, then their distance in that representation space should be smaller.

The characteristics need not be quantitative measures themselves, but are often quantified by the researchers. Apart from the weighting of each separate characteristic, also the classes of each characteristics must be quantified, in order to compute a distance. Some techniques are using the basic information (nominal, ordinal or metric in nature) and look for a joint quantification of weights and classes, such that a representation of the similarities or dissimilarities is found in a reduced representation space. In our case, we have used a quantification on the basis of heuristic rules, during a process of matching of a subset "by hand" and of an analysis of the errors in the data.

The distance function can be written as follows:

$$D = \sum_i c_i \, \delta(\alpha_i, \beta_i)$$

In this formula c_i is the weight for each pair of matching variables i. $\delta(\alpha_i,\beta_i)$ the distance between the two classes within the pair. The final distance D is the sum of the weighted distances δ_i.

Pairs that match completely should have a distance of zero. However, the match between time and date of the accident and of hospitalization are always different. Therefore, some relaxation of the criterion is used. (Narrow) margins are selected for a zero distance between these characteristics.

If α and β are both known and equal, δ is zero. If sufficiently different, then δ is one. If the difference is small, the value is between zero and one and depending on the difference. In case α or β is unknown also some value between zero and one is chosen.

The value of δ_i depends on information about errors and differences between values on the

variable i for pairs that were matched with certainty, during the matching by hand. Those pairs that agreed on all characteristics but one, were used to specify the δ_i-value. The sets investigated consisted of the data for one quarter of a year. For the AVV-BG databank 6700 records were used and for the SIG-databank 5679.
The value of c_i depends on:

- the probability of an error
- the resolution of the variable (the number of possible values)
- the distribution over the possible values

Table 2. shows the differences in the scores on the variable 'epoch' (the combination of time and day of the accident or hospitalization), for the matching 'by hand'.
In both databases the probability of a male is approximately 0.68. Therefore, the probability of a random match on sex is $0.68^2 + 0.32^2 = 0.56$. For hospital the probability of such a random match is 0.01.
As an example of the possible effects of random matching on the results, the following calculation that is based on these values of the four key-variables gives an insight. The estimated probability of a random (perfect) match on the basis of the four characteristics is $0.56 \times 0.01 \times 0.003 \times 0.02 = 0.00000034$. For the two test sets the expected number of random matches amounts $6700 \times 5679 \times 0.00000034 = 12.9$ matches.

Epoch-difference	Number
1-90 days negative	3
0-1 dag negative	27
0-1 hour positive	189
1-2 hour positive	545
2-3 hour positive	558
3-4 hour positive	419
4-5 hour positive	149
5-6 hour positive	73
6-7 hour positive	23
7-12 hour positive	39
12-24 hour positive	20
1-2 days positive	10
2-3 days positive	8
3-10 days positive	10
10-90 days positive	13

Table 2. *Differences in epoch for the first quarter of 1993.*

It can therefore be concluded that the number of 3 negative matches in the first row of Table 2 and the 23 discrepancies in the last two rows can indeed be caused by incorrect matching by use of the other three variables. For the 27 observations in row 2, it is more likely that a coding error has been made.

On the basis of these results, the value of δ is chosen one for all values not between -1 day and plus three days. Those pairs between -1/2 hour and three hours will get a value of zero. Small different positive values are given to pairs with differences within one day and between one and three days. Given the high value of c, all pairs with a value of $\delta=1$ will not be matched. The number of records that should have been matched, but that will not be matched for this reason is estimated to be some twenty records.
Similar procedures have been applied to the other variables. On the basis of these analyses, c-values and δ-values are determined.

3. The matching procedure.

The matching procedure could also be called a mating procedure. A possible mate should have an acceptable distance. The 'best' mate for a record in one data set is the record in the other data set that has the smallest distance. But that possible mate might itself have a more favourable mate in the other data set. Furthermore, distances (even zero distances) need not be unique.
To solve these problems and to avoid unrealistic (time consuming) procedures based on calculation of all possibilities, a strategy has been selected that assures the possibility of an acceptable match and meets certain computation time criteria that makes application to data sets of the size at hand realistic.
In this procedure, the records in each data set are ordered according to epoch and given a rank number.
Furthermore, during the matching procedure each record gets a matching status indicator (undecided, matched, not matchable), two pointers to records in the other data set, two distances to the records pointed to and a selectivity value. At the beginning the status indicator is initiated at the value 'undecided' and the distances at a maximal value.

In principle all records in each set should be compared with all records in the other set. However, ordering according to epoch makes it possible to reduce the total number of comparisons with a factor 100 if records outside a certain range are ignored. At each comparison, the distance is computed and recorded in one of the two distance fields, if this distance is smaller than a previous value. The corresponding pointer field is filled with the rank number of the record from the other set. This is done in both data sets if applicable.
At the end of this procedure, for each record in each set there is a pointer to the most favourable mate, together with the associated distance and a second pointer and distance to the next favourable mate.

The next step is to check for each record in each set whether the smallest distance is acceptable. If not, then that record gets the status 'not matchable'.
The actual matching procedure is as follows:

a) start with first record in set 1 that is undecided;
b) look at the first mate (record with smallest distance in the other set);
c) check if the indicator of that mate is 'undecided'; if 'yes', then d1), else d2)
d1) if the first mate of the record in the other set is the starting record, then the records will be matched, else make this mate the starting record and goto b);
d2) if the second mate is not 'undecided', then the (start)record is 'not matchable'; if 'undecided', then goto d1).

It is proven that the change in the choice of the starting record in d1) is not circular and therefore ends in a finite number of steps.
For each record of a matched pair, the difference between the distance to the first and second mate is computed. The selectivity measure for a matched pair is subsequently computed as the minimum of these differences and added to both records, together with

their distance and the pointer to the other record.

4. Results.

Results of the automated procedure are compared to the outcomes of the matching by hand. Coefficients were adjusted and some programme bugs eliminated. The final results were satisfactory. Only a small proportion of the records matched by hand (in which also additional heuristic rules are used) were missing. The method was then applied to the data for 1992 and 1993. The results for both years were rather similar and in agreement with the outcomes of the quarter that had been used for correction of the procedure.
A number of checks was carried out to evaluate the outcomes in more detail.

4.1 Checks on the results.

In an ideal case, matched pairs should have a minimum distance and a maximum value on the selectivity measure, while the reverse should be the case with the records that were not matched.

	S=0-39	40-79	80-119	120-159	160+	Total
D = 0	23	86	2302	2708	940	6059
1-40	11	246	880	619	108	1864
41-65	76	690	1049	286	17	2118
66-100	193	336	118	8	1	656
101-130	399	180	30	2	0	611
131-200	2819	206	7	1	0	3033
200+	78	18	0	0	0	96
Total	3599	1762	4386	3624	1066	14437

Table 3. *Distance- and selectivity categories for matched records from 1993.*

Table 3. gives an overview of the relation between distance (D) and selectivity (S) for one year. It contains all matched records, ranging from very likely correctly matched till very unlikely correctly matched (distance 200+). Most of these records (6059) have distance zero, and 98% of these have a selectivity of 80 or more. For 86 % in the distance class 1-40 the selectivity is still higher than 80. For the classes with a higher distance we see on average a decrease in selectivity. Almost all records above distance 100 have low selectivity. On the basis of this analysis records got a 'matching quality measure' (rank A through F), depending on the combination of distance and selectivity.
The highest rank A (almost certain) is given when D=0 and S>79; rank B (very likely)

when D=0 and S between 40 and 79 or D between 1 and 40 and S>39; rank C (likely) when D between 41 and 65 and S>39; rank D (reasonable) when D between 66 and 100 and S>39; rank E (doubtful) when D between 101 and 130 and S>39; all other records got rank F (almost certainly not correct).
In all further work, this distinction in quality has been taken into account, in order to find the most likely estimates (e.g. of under-reporting or bias in databanks).
Other checks regarded the coding of accidents and the severity code in the SIG-databank.
Finally a comparison was made with the results of a similar pilot-matching from 1987.

4.2 The ' footprint' method.

Furthermore, estimation of the number of records for the cells of Table 1. took place. This was done, not only using the records that were not matched or matched with high probability, but also the records that were matched with low probably, correcting for the over-estimation of these numbers.
Classes of pairs, matched with higher and lower certainty, were treated separately in the analysis. For the class with a perfect match and therefore very high probability of correctness, the mismatch on other variables than the key-variables was used to measure the probability of inconsistencies between scores. The cross-table of scores on such a variable in both databanks for only the correctly matched pairs was used to get a profile of similarities and dissimilarities in both scores that were not caused by random matching. This profile was called a 'footprint'. The footprint was further used to estimate the number of correct matches in the groups with lower certainty. The method was applied to the data from 1992 and 1993 combined, using information about the mode of transportation of the victim, although the categories of this extra variable are partly different in both databanks.

The main procedure is as follows.
For the pairs with maximal likelihood of matching (rank A), a comparison is made between the codes for traffic mode in the two records. It is assumed that, if these codes differ, this is caused by random error, by deletion (unknown) or systematic differences in coding instruction. Because it regards (almost) surely correct pairs, we call this matrix the 'footprint' of the table.
For each of the sets with less likely matchings the same can be done. However, here random matches are expected to disturb the footprint. On the assumption of 'complete random matching' (and therefore independent row and column values), we can compute the expected cell-values from the given marginals of such a table. It is assumed that the observed table (T) is a combination of the footprint (F) and the random table (R): $T = a \cdot F + (n-a) \cdot R$, where n is the total number of pairs, and a is the number of correct pairs. The most likely combination (in terms of the minimum Chi-square) of the footprint table and the random table results in the respective estimates of the correct matches (a) and incorrect matches (n-a).

Hospitalized victims	A = 0	10 - 40	44 - 65	66 - 100	101 - 130	131 - 200
Motorized	11302	3237	3069	785	649	2342
Perc. correct	100%	100%	100%	79%	40%	14%
Non-motorized	839	247	310	180	394	2052
Perc. correct	100%	100%	100%	51%	15%	1,6%

Table 4. *Estimated number of correctly matched records in two main SIG-categories of victims, as a function of distance, for 1992 and 1993 together.*

Of course, using this method it is not possible to detect which records are correct and which are not, but only to estimate the number of correct matchings for each quality class. The estimated number of random matches in Class B and C turned out to be negligible. 73% of Class D was correctly matched and 30% of class E.
Table 4 gives an indication of the outcomes of this procedure for aggregated traffic modes. It can be seen that the estimated number of correctly matched pairs for the records with small distances, up to 65 is 100% for motorized as well as non-motorized victims. For the other categories these percentages are lower and decreasing with distance. Especially or the non-motorized victims this is the case. Only 16% has a distance larger than 100. For the motorized victims still 40% has a distance between 100 and 130.

5. Conclusions.

Procedures has been developed that can effectively be used to estimate the total number of hospitalized victims by comparing the information from the official road safety statistics and additional information from hospital records. These procedures can be generalized to all kinds of situations where matching of databanks is necessary and matching by hand is too time consuming.
Although there was no unique key that matches the records and makes estimation of under-reporting possible from the information of the (almost complete) database from the hospitals directly possible, it was still possible to estimate this under-reporting, using a technique called the 'footprint' method. Also this procedure has a wider range of possible applications.
The outcomes of the study have been used in the Netherlands to revise the reporting of hospitalized victims. The result was that considerably higher numbers of victims are now officially reported. As a consequence of this policy, also the trends in these numbers will be less favourable over the last years, compared with the originally published figures.
On the basis of the outcomes of the study it was also possible to estimate the bias in the database of the official road statistics with regard to characteristics such as traffic mode and region. In principal this is also possible for other characteristics. The outcomes for safety itself will be reported in a separate publication.

Simulation of car-pedestrian impacts. A new human-body mathematical model

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1 Introduction

In the European Union (EU) around 10,000 pedestrians are killed each year and 90,000 seriously injured, resulting in substantial economic losses due to fatalities and long-term consequences. The improvement of pedestrian safety is therefore considered a priority in traffic safety strategies (EEVC, 1985; ETSC, 1997a). The relative world-wide frequency of pedestrian fatalities varies approximately from 10 to 50 %. These differences are related to a number of factors such as road user behavior, legislation, education and training, social environment, road traffic environment, and vehicle safety. There are thus several different strategies which have to be undertaken to achieve acceptable safety for these road users and reduce the incidence and the severity of these accidents.

Since pedestrians are unprotected in vehicle impacts, they are considered a high risk population. It is extremely hard to find relevant vehicle designs to reduce the injury risks and severities. This paper gives a summarized description of a model which could serve as a useful tool for studying different countermeasures to reduce the severity of accidents.

Since the 1970's, many studies on injury mechanisms, tolerance levels, influences of the vehicle design on impact responses, safety countermeasures and assessment techniques have been carried out. Pedestrian substitutes such as biological specimens, mechanical dummies and mathematical models have been used in these studies. Data from real accidents as well as from simulations have served to analyze the influence of vehicle designs. The bumper, bonnet and windscreen have been shown to be the major injury-producing car structures.

During the past two decades significant reductions in pedestrian fatalities have been achieved in Europe (ACEA, 1992) and in the United States (NHTSA, 1992). This tendency is mainly due to improved traffic planning. However, new aerodynamic designs of cars may have

contributed to the reduction of pedestrian injuries. So far, there is no statistical study to prove injury reduction by changes in car-front shape. However, the findings from experimental studies (EEVC, 1985; NHTSA, 1993) support the fact that the potential benefit may obtain from changes in front-end shape with rounded bonnet edges, smooth surface and low bumper, which is in accordance with the principle of the aerodynamic design of cars. ETSC (1997b) has recently estimated a potential reduction of fatalities by 7% if pedestrian-friendly car designs were to be introduced.

The growing use of small city cars in urban areas of European countries has entailed higher risks for pedestrians as small city cars have stiffer front regions than bigger cars to achieve acceptable compatibility in crashes with the latter (Hoffmann and Renner, 1994; Maurer et al., 1996). Therefore, there is an increasing concern about the city car designs also for pedestrian protection.

1.1 Injury epidemiology

Vehicle impacts have been confirmed to be the main cause of fatal and severe injuries (Ashton and Mackay, 1979). The secondary impact, the pedestrian-ground contact may of course also contribute to severe injuries, depending on which body area hits the ground first and at what velocity.

Pedestrians struck at impact speeds less than 25 km/h usually sustain only minor injuries. Serious injuries occur frequently at velocities between 25 and 55 km/h whilst at velocities greater than 55 km/h the pedestrians are most likely to be killed (Ashton, 1982) (fig. 1).

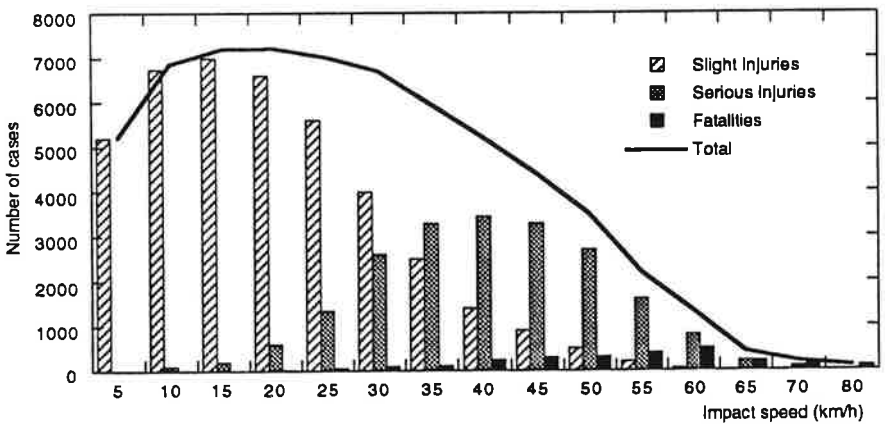


Figure 1.The injury severity distribution as a function of impact speed (based on Ashton, 1982).

The head and the lower extremities have been found to be the most frequently injured. At impact speeds less than 30 km/h, there is a high risk of modest leg/knee injuries (AIS 2-3) and these may result in long-term or permanent disabilities. The risk of fatal head injuries increases rapidly at impact speeds greater than 40 km/h.

1.2 Impact dynamics

The kinematics of the pedestrian and the distribution of injuries in car-pedestrian impacts are influenced by impact speed, car front shape and stiffness, bumper height, bonnet height and length, size of the pedestrian, and standing position of the pedestrian relative to the car (fig. 2).

When an adult is struck by a car front, the first contact occurs between the bumper and either the leg or knee-joint area, followed by the thigh contacting the bonnet edge. The lower extremity of the body is accelerated forwards, which causes the upper body to rotate relative to the car. Consequently, the pelvis and chest are impacted by the bonnet edge and top, respectively. The head may hit the bonnet or windscreen at a velocity estimated as a ratio of 0.7 - 0.9 to the car-travel speed for big cars (Pritz, 1983) and 1.1 - 1.4 for small cars (Cavallero et al., 1983). The victims then fall onto the ground. During the course of car-pedestrian contacts, the whole body wraps around the front of the car. The contact location of the upper body segments can be estimated by the wrap-around distance (WAD) along the car-front surface (fig. 2).

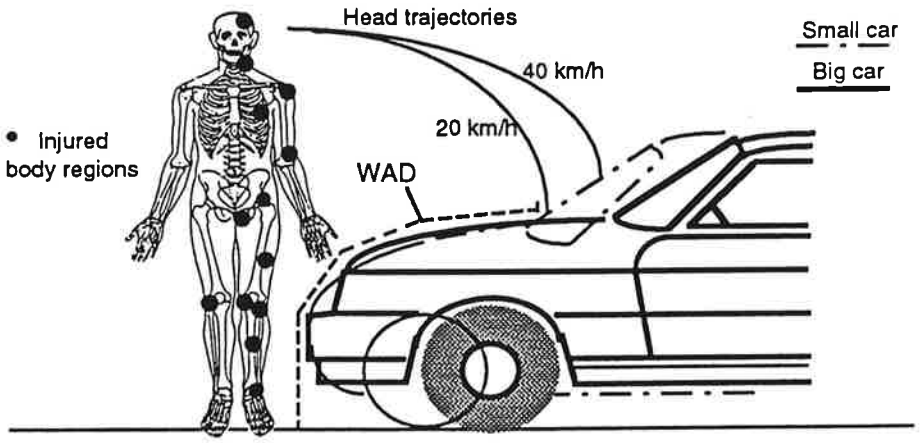


Figure 2. Distribution of injuries to an adult pedestrian in frontal car-pedestrian collisions, trajectories of the head with respect to small and big cars, changes of the locations of head impact at varying impact speeds, and the WAD (wrap around distance) (from Yang, 1997).

1.3 Injury and protection assessment techniques

To investigate the pedestrian impact response and injury mechanisms, and to assess car front aggressiveness, three different models can be used: human cadavers (biological models), mechanical or mathematical models. During the past decades, mainly biological and mechanical models have been used.

The use of cadavers in crash tests is mainly relevant for the study of the kinematics during an impact for different body segments, and to get insight into injury mechanisms.

Experiments with crash dummies are carried out to assess the interaction between the vehicle and the human body during the accident, and to evaluate the protective capacity of vehicles and safety devices. During the last decade, ongoing efforts have been oriented towards developing a new pedestrian dummy (Aldman et al., 1986).

A subsystem test method to assess the aggressiveness of passenger car-fronts to pedestrians has been proposed by EEVC (1994) and has been suggested as the European regulation. Lawrence et al. (1993) calculated a cost-benefit ratio of 7.5:1 if the EEVC subsystem test procedure were implemented, a result which today is widely discussed not least within the automotive industry. The configurations, requirements and thresholds for the subsystem tests are summarized in fig. 3.

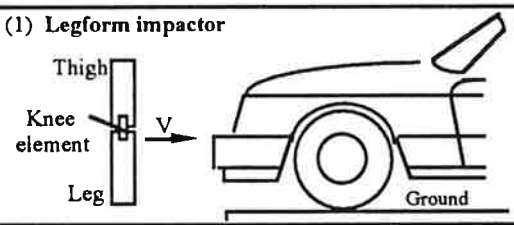
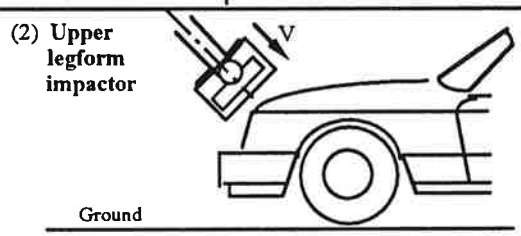
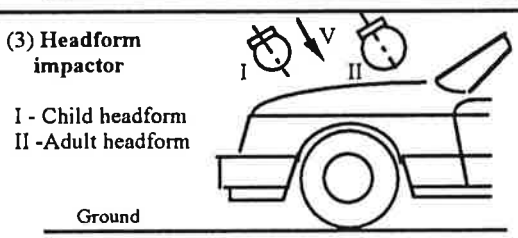
Configuration of subsystem tests	Test requirement	Threshold (at 40 km/h)
(1) Legform impactor 	- knee bending angle - knee shearing dislocation - acceleration at upper end of the tibia	< 15° < 6 mm < 150 g
(2) Upper legform impactor 	- impact force - bending moment	< 4 kN < 220 Nm
(3) Headform impactor I - Child headform II -Adult headform 	- Head Performance Criteria (*HPC*) - Nine tests shall be carried out with each headform impactor at positions judged to be the most likely to cause injury	< 1000

Figure 3. The EEVC impactors for pedestrian subsystem tests (based on EEVC, 1994)

1.4 Mathematical modeling of vehicle-pedestrian impacts

With the rapid development of computer hardware and software, mathematical models are increasingly being used as a complement to experimental methods, and play an important role in traffic safety research. Mathematical models can be used to analyse accidents, to design safety devices, to study crashworthiness and impact responses of the human body, as well as to assess injury risks in various types of accidents. Advantages of mathematical models are the exact repeatability of a simulation, and the possibility to easily conduct parameter studies. The mathematical models allow calculation of the detailed physical quantities within a biological structure. The results from validated mathematical models may supplement the data obtainable in crash tests.

Since the 1970's, a number of mathematical models have been developed for simulations of vehicle-pedestrian impacts. However, in these simulations, the impact responses of the models appeared excessively stiff, compared with the impact responses of a human subject since the models usually were based on crash dummies.

There is thus still a need to develop and validate a realistic human-body model. The knee joint and leg segment have to be adequately represented in the model so that it will allow the simulation of the knee responses associated with leg fracture, the investigation of the influence of car-front end on head responses to bonnet/windscreen impacts, and the prediction of the risk of pedestrian injury in car-pedestrian impacts. Well validated biofidelic mathematical models should be promising for the analysis of pedestrian impact responses and the study of the performance of the shape, stiffness, and design features of a vehicle, and the influence of the collision speed.

The aim of this study is to develop and validate a 3D mathematical model of the human-body to simulate car-pedestrian impacts. The model may be used to predict the risk of pedestrian injuries, to evaluate the performance of car fronts, and to study the influence of the collision speed.

2 Methods

A human body mathematical model was developed and used to simulate car-pedestrian impacts (fig. 4). The model uses the commercial software MADYMO 3D and consists of fifteen body segments connected by fourteen joints, including two human-like knee joints and

two breakable leg segments. The characteristics of the body segments and the joints were based on available biomechanical data. The car-front model was based on that of Ishikawa et al. (1993). A detailed description of the model can be found in Yang and Lövsund (1997).

The validity of the model was evaluated by comparing results from computer simulations and published impact tests with cadavers. Available materials from tests include kinematics of pedestrian substitutes and measured injury-related parameters.

A parameter study has so far been performed by means of a factorial test with the following car-front parameters: bumper height, bumper stiffness, bumper lead distance, height of hood-edge, hood-edge stiffness, and impact speed. The results have been used to evaluate the effects of these parameters on impact force, knee rotation angle, knee ligament strain, head impact force, HIC value, and head angular acceleration.

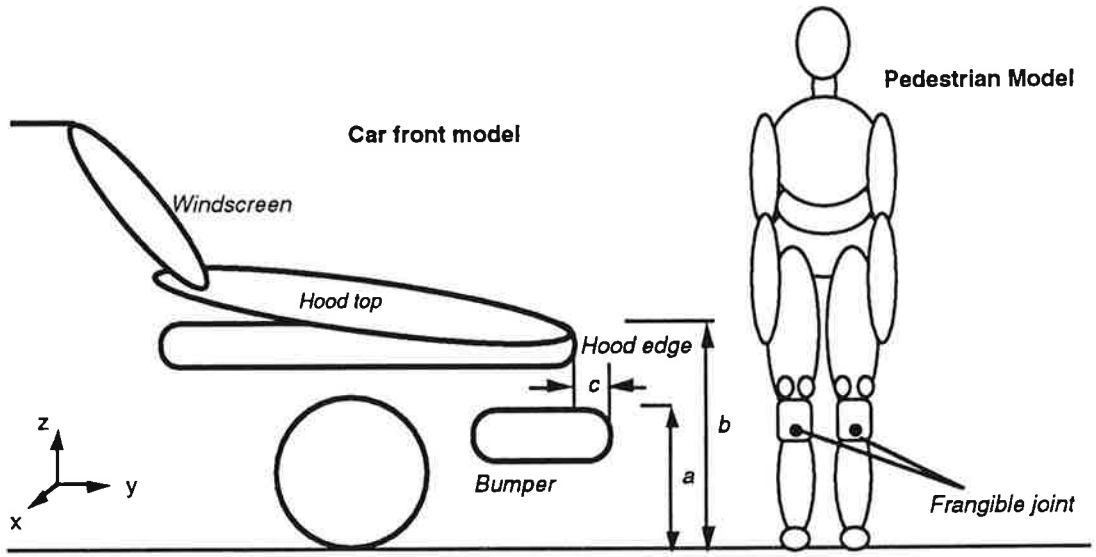


Figure 4. The simulation set-up for the car-pedestrian impact tests; a = bumper height, b = hood edge height, c = bumper lead distance.

3 Results

Two examples of the overall kinematics of pedestrian substitutes in the impact tests and simulations at impact speeds of 32 and 39 km/h are presented in fig. 5. The spatial motion of the pedestrian substitutes found in the impact tests is well predicted with the mathematical

4 Discussion

Pedestrian protection is one of the priority items in traffic safety strategies (EEVC, 1985; ETSC, 1997a,b) due to a high incidence of vehicle-pedestrian accidents and a high proportion of pedestrian fatalities among all killed road users. Furthermore there is a high risk of permanent disability. Effective countermeasures require knowledge about pedestrian injuries and injury mechanisms in accidents. Knowledge about injury mechanisms of pedestrians in car impacts has mainly been achieved from tests with cadavers. Cadaver tests, however, can not be used for extensive study of safety countermeasures due to ethical problems and high cost of such tests. Several types of dummies have therefore been developed to evaluate new countermeasures. So far none of them have been found appropriate to simulate responses of pedestrians in car impacts due to biofidelity and repeatability problems.

There exist several pedestrian mathematical models. The earlier pedestrian models show a limited biofidelity, and only allow for the prediction of the kinematic behavior. None of the previous models were used in the evaluation and development of countermeasures. Consequently, there is an increasing need for pedestrian mathematical models with improved biofidelity which are suitable for the prediction of the kinematic behavior and injury risks of pedestrians as well as for the evaluation of safety concepts in the early stages of car designs.

The developed human-body 3D mathematical model is able to simulate the responses of pedestrians in car impacts. The model provided valid results for car-pedestrian impacts at speeds of 25 to 39 km/h, which are the most common in real world accidents.

Important injury-related parameters can be calculated by means of the model, including impact forces, accelerations for different body segments, HIC, transverse dislocation and contact forces between articular surfaces, knee-ligament strain, and knee-bending angle. It is therefore considered a valuable tool to predict the risk of pedestrian injuries in accidents.

The pedestrian model is sensitive to changes in car-front parameters and impact speeds, and is thus also a useful tool for analyzing pedestrian responses, especially to the lower extremities, in different impact conditions and for studying the performance of the vehicle exterior as it relates to pedestrian protection.

Acknowledgement

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model. It shows good flexibility in the lateral rotation of the body segments. The time history and the location of the head impact to the windscreen are correctly simulated.

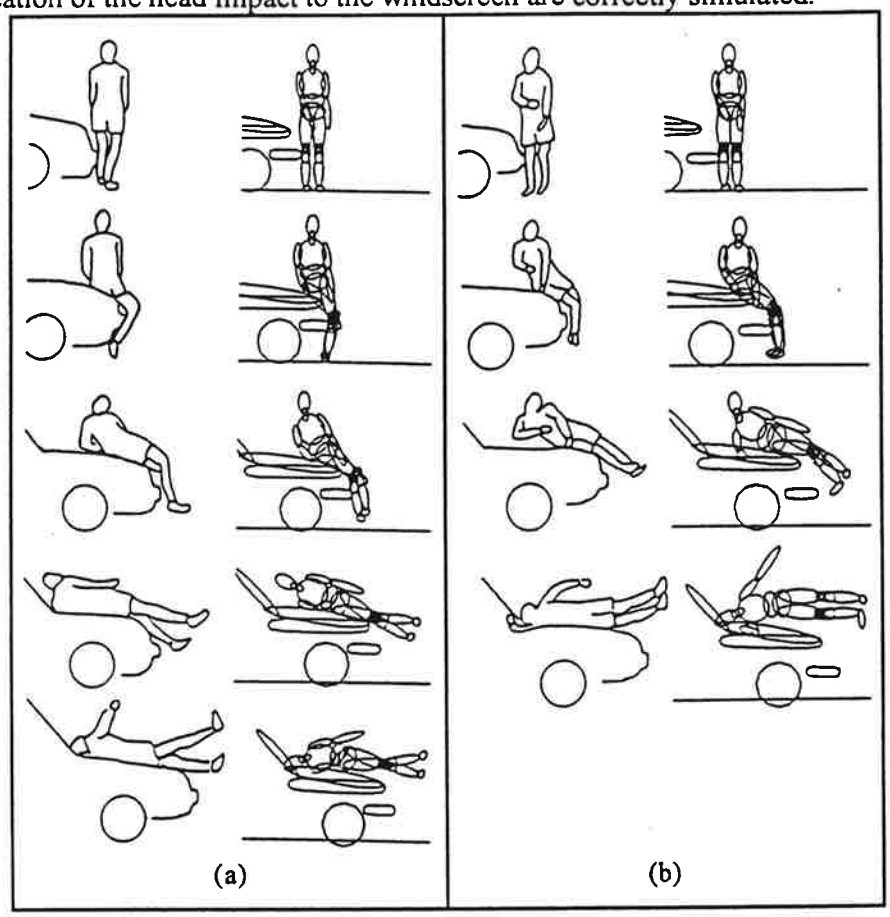


Figure 5. Comparison between the tests and corresponding simulations for kinematics of the pedestrian substitutes at impact speeds of (a) 32 km/h, and (b) 39 km/h; time step Δt =50 ms.

A comparison between test and simulation at 32 km/h for the accelerations of the leg, pelvis and head indicated that the accelerations of the leg and head measured in the test are well predicted in the simulations in terms of the peak values and the curve wave shapes. The pelvis acceleration was underestimated in the simulation. A comparison between test and simulation at 39 km/h for the accelerations of the thorax, pelvis and head indicated that pelvis and head accelerations from the test were very similar with the corresponding results from the simulation regarding the peak values and curve wave shapes. The peak values of the thorax acceleration were underestimated in the simulation.

The model is sensitive to impact speed for almost all injury-related parameters. The lower extremity in the model is sensitive to the changes in bumper stiffness, bumper height, bumper lead distance, hood-edge height. The parameter study indicate significant effects of bumper height, bumper stiffness, bumper lead distance, and hood-edge height on responses of the knee-leg complex in a lateral impact to the leg. The head responses appear to be dependent primarily on hood-edge height.

5 References

ACEA (1992). Pedestrian Accidents in Europe, Development & Challenges. European Automobile Manufacturers Association, Brussels, Belgium.

Aldman, B., Kajzer, J., Cesari, D., Bouquet, R., Zac, R. (1986). A New Dummy for Pedestrian Test. Proc. of the Int. Technical Conf. on Experimental Safety Vehicles, Oxford, England, July 1 - 4, 1985. US DOT NHTSA, USA. pp. 176 - 185.

Ashton, S. J. (1982). Vehicle Design and Pedestrian Injuries. Chapter 6, in Pedestrian Accidents. Edited by Chapman et al. John Wileys & Sons Ltd.

Ashton, S. J. and Mackay, G.M. (1979). Car Design for Pedestrian Injury Minimization. Proc. of the 7th Int. Technical Conf. on Experimental Safety Vehicle, Paris, June 5-8. US Dept of Transportation, NHTSA. pp. 630-640.

Cavallero, C., Cesari, D., Ramet, M., Billault, P., Farisse, J., Seriat- Gautier, B. and Bonnoit, J. (1983). Improvement of Pedestrian Safety: Influence of Shape of Passenger Car-Front Structures Upon Pedestrian Kinematics and Injuries: Evaluation Based on 50 Cadaver Tests. Proc. of the Pedestrian Impact Injury & Assessment. SAE Int. Congress & Exposition, P-121, Detroit Michigan, February 28-March 4. SAE, Warrendale, PA, USA. pp. 225-237.

EEVC (1985). Pedestrian Injury Protection by Car Design. Proc. of the Tenth Int. Tech. Conf. on Experimental Safety Vehicles, Oxford England, July 1-4, 1985. US Dept. of Transportation, NHTSA, USA. pp. 965-976.

EEVC (1994). Proposals for Methods to Evaluate Pedestrian Protection for Passenger Cars. Report, European Experimental Vehicle Committee, working group 10.

ETSC, (1997a). A Strategic Road Safety Plan for the European Union. *European Transport Safety Council*, Brussels.

ETSC, (1997b). Promoting Road Safety in the EU, the Program for 1997-2001. *European Transport Safety Council*, Brussels.

Hoffmann, R. and Renner, A. (1994). City Cars - A New Challenge for Occupant Safety Systems. Proc. of the 14th Int Tech. Conf on Enhanced Safety of Vehicles. Munich, Germany, May 23-26, 1994. US Dept of Transportation, NHTSA, pp 684-688.

Ishikawa, H., Kajzer, J. and Schroeder, G. (1993). Computer Simulation of Impact Response of the Human Body in Car-Pedestrian Accidents. Proc. of the 37th Stapp Car Crash Conference, November 8-10, San Antonio, Texas. SAE, Warrendale, PA, USA. pp. 235-248.

Lawrence, G. J. L., Hardy, B. J. and Lowne, R. W. (1993). Costs and Benefits of the EEVC Pedestrian Impact Requirements. Project Report 19, Transport Research Laboratory, UK.

Maurer, D., Thompson, G.M., Müller, R., Graffe, M., Weyersberg, A. (1996). Safety Concepts for Very Small Vehicles, Example: Opel MAXX. Proc. of the 15th Int Tech.

Conf on Enhanced Safety of Vehicles. Melbourne, Australia, May 13-17, 1996. US Dept of Transportation, NHTSA.

NHTSA, (1992). Traffic Safety Facts 1992, Pedestrians. National Highway Traffic Safety Administration, US Dept of Transportation, Washington DC, USA.

NHTSA (1993). Pedestrian Injury Reduction Research. National Highway Traffic Safety Administration, US Dept of Transportation, Washington DC, USA.

Pritz, H. B. (1983). Experimental Investigation of Pedestrian Head Impacts on Hoods and Fenders of Production Vehicles. Proc. of the Pedestrian Impact Injury & Assessment. SAE Int. Congress & Exposition, P-121, Detroit Michigan, February 28-March 4. Society of Automotive Engineers, Warrendale, USA. pp. 67-76.

Yang, J.K. (1997). Injury Biomechanics in Car-Pedestrian Collisions: Development, Validation and Application of Human-Body Mathematical Models. Doctoral thesis. Dept. of Injury Prevention, Chalmers University of Technology, Göteborg, Sweden

Yang, J.K. and Lövsund, P. (1997). Development and Validation of a Human-Body Mathematical Model for Simulation of Car-Pedestrian Impacts. Proc. of *the Int. IRCOBI Conference on the Biomechanics of Impacts*. Hannover, Germany, IRCOBI Secretariat, Bron, France.

Relative collision safety in cars

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Abstract

We propose a new model for relative collision safety in cars. Our present research are restricted to head-on crashes between two cars. When two cars crash they are exposed to the same force, but the damage severity is different depending on various factors such as car mass, change of speed and design of the car. The underlying mathematical model is partially founded on birth processes. Police and hospital data are used to explore the relationships in our model.

1 Introduction

In this paper we investigate the possibility of extracting a relative collision safety risk, α, between different car models. It is an interesting problem to study because almost everyone drives a car in their every-day-life and most people care about their own, and hopefully others, safety in case of a collision. One question of interest might be how safe one car model, for example Volvo, is compared to another model, for example Saab, and this is what we call the relative collision safety risk. This work is inspired by Tingwall and others work at the insurance company Folksam , see Hägg et al (1992). We study similar questions, but our model is new. The aim of this study is to examine this car model dependent risk, α. The analysis is restricted to head-on crashes between two cars in which at least one of the two drivers involved was injured. Data from Statistics Sweden (SCB) containing traffic accidents reported to the police during the years 1992-1993 are used to explore the relationships in our model. Known quantities from this data set are car model, car mass and the injury of the driver.

The injuries are classified according to:

0: The driver is unhurt.

1: The driver is mildly hurt.

2: The driver is seriously hurt.

3: The driver is dead within 30 days.

The injury classification according to the police are completed with the hospital injury register to improve the classification.

2 Physical Background

When two cars crash head-on into each other they are exposed to the same force, but the damage severity is different. The difference is depending on various factors such as the masses of the two cars involved, the change of speed that the vehichle undergoes and the design of the car - a measure connected to car model. In Evans (1994a,b) relationships between driver risk and car mass is studied. This study is an effort to absolute how much of the injury risk that depends on car model.

I call the two cars involved in a crash car number one and car number two. The enumeration depends only on where in my database they appear. Let

m_1 = the mass of car number one
m_2 = the mass of car number two.
v_{11} = the speed of car number one before the crash.
v_{21} = the speed of car number two before the crash.
v_{12} = the speed of car number one after the crash.
v_{22} = the speed of car number two after the crash.
Δv_1 = the change of speed that car number one undergoes in the crash
Δv_2 = the change of speed that car number two undergoes in the crash

Newtonian mechanics helps us to tie the two cars in the crash together. The law of conservation of linear momentum states that linear momentum before crash equals linear momentum after crash. I.e.

$$m_1 v_{11} + m_2 v_{21} = m_1 v_{12} + m_2 v_{22}$$

$$\Delta v_2 = \frac{m_1}{m_2} \Delta v_1$$

3 Notations

Let θ be a nuisance parameter connected to the change of speed that the vehicle undergoes in the crash. Let

θ_1 be proportional to Δv_1 and
θ_2 be proportional to Δv_2 i.e. proportional to $\frac{m_1}{m_2}\Delta v_1$

Further I let α be my so called design parameter. It is my parameter of interest and it is connected to car model. Each car model corresponds to a particular α. We have grouped versions of the same car model together, i.e there is one α for Volvo, one for Saab etc. This car model dependent risk, α should be interpretended in the following way: the smaller the alpha, the more secure is the car model.

Let t be a measure on how much violence the driver is exposed to in the crash, i.e. t depends on car mass, change of speed and car model: $t = t(m, \Delta v, \alpha)$.

As usual we let P(.) stand for probability:

$P_0(t)$ = P(the driver will end up in injury class 0 exposed to violence t)
$P_1(t)$ = P(the driver will end up in injury class 1 exposed to violence t)
$P_2(t)$ = P(the driver will end up in injury class 2 exposed to violence t)
$P_3(t)$ = P(the driver will end up in injury class 3 exposed to violence t)

4 Model formulation

Trying to find a suitable mathematical model the following criteria were put: $P_0(t)$ should be cloose to one when t is small and then decrease to zero when t increases. This means that if there is a gentle crash the probability should be close to one that the driver will be unhurt. On the opposite $P_3(t)$ should be cloose to zero when t is small and then increase to one when t increases. $P_1(t)$ and $P_2(t)$ should increase from zero to a maximum and then decrease back to zero again. Of course $P_1(t)$ and $P_2(t)$ vary only between zero and one. $P_1(t)$ should be shifted towards the left compared to $P_2(t)$.

All our demands are fulfilled if we model this as a pure birth-process where we let the states correspond to the injury classes. This means that we have a birth process where the states have the following interpretation:

State	Interpretation
0	The driver has ended up in injury class 0
1	The driver has ended up in injury class 1
2	The driver has ended up in injury class 2
3	The driver has ended up in injury class 3

Introducing a birth process forces us to introduce further nuisance parameters, namely the birth rates: λ_0, λ_1, λ_2, λ_3.

5 Calculations

Introducing a birth model we have now the possibility to calculate the transition probabilities P_0, ..., P_3. Kolmogorovs Forward Equations for a pure birth process states that:

$$P_{ii}(t) = e^{-\lambda_i t} \qquad i \geq 0$$

$$P_{ij}(t) = \lambda_{j-1} e^{-\lambda_j t} \int_0^t e^{\lambda_j s} P_{i,j-1}(s) ds \quad j \geq i+1$$

In our model we always start at state 0 (we assume that the driver is unhurt before the crash). This means that $i = 0$ all the time and the index i is not necessary. Kolmogorovs Equations simplifies to :

$$P_0(t) = e^{-\lambda_0 t}$$

$$P_j(t) = \lambda_{j-1} e^{-\lambda_j t} \int_0^t e^{\lambda_j s} P_{j-1}(s) ds \quad j \geq 1$$

While state number three is the highest state in our model, the only possible value of λ_3 is zero. Solving the equations (with $\lambda_3 = 0$) gives us:

$$P_0(t) = e^{-\lambda_0 t}$$

$$P_1(t) = \frac{\lambda_0}{\lambda_1 - \lambda_0} e^{-\lambda_0 t} + \frac{\lambda_0}{\lambda_0 - \lambda_1} e^{-\lambda_1 t}$$

$$P_2(t) = \frac{\lambda_0 \lambda_1}{(\lambda_1 - \lambda_0)(\lambda_2 - \lambda_0)} e^{-\lambda_0 t} + \frac{\lambda_0 \lambda_1}{(\lambda_0 - \lambda_1)(\lambda_2 - \lambda_1)} e^{-\lambda_1 t} + \frac{\lambda_0 \lambda_1}{(\lambda_0 - \lambda_2)(\lambda_1 - \lambda_2)} e^{-\lambda_2 t}$$

$$P_3(t) = 1 - \frac{\lambda_1 \lambda_2}{(\lambda_2 - \lambda_0)(\lambda_1 - \lambda_0)} e^{-\lambda_0 t} - \frac{\lambda_0 \lambda_2}{(\lambda_0 - \lambda_1)(\lambda_2 - \lambda_1)} e^{-\lambda_1 t} - \frac{\lambda_0 \lambda_1}{(\lambda_0 - \lambda_2)(\lambda_1 - \lambda_2)} e^{-\lambda_2 t}$$

6 Estimation

The vector of parameters that we want to estimate is $\boldsymbol{\alpha} = (\alpha_1, \alpha_2, ..., \alpha_m)$, where m eqals the number of car models in the study. To estimate α we have to estimate several nuisance parameters, namely $\boldsymbol{\theta_1} = (\theta_{11}, \theta_{12}, ..., \theta_{1n})$, $\boldsymbol{\theta_2} = (\theta_{21}, \theta_{22}, ..., \theta_{2n})$, where n eqals the number of crashes in the study, and the birth rates $\lambda_0, \lambda_1, \lambda_2$. As described above, λ_3 must equal to zero. Further we standardize λ_0 to one. Using that $\theta_{2j} = \frac{m_{1j}}{m_{2j}}\theta_{1j}$ leaves us with $k+n+2$ parameters to estimate.

Let us study one example of how we describe the probabilities after one crash, for example crash number 109 in our data set. Letting l stand for the number of the crash in our data set, $l = 109$ in this example ($l = 1, ..., n$). In every crash there are two cars involved: car number one and car number two. We let k be the index connected to the number of the car, i.e. $k = 1, 2$.

	Car number one	Car number two
	$k = 1$	$k = 2$
Crash number	$l = 109$	$l = 109$
Car model	Vw	Volvo
Relative risk	α_{Vw}	α_{Volvo}
Injury class	j = 1	j = 0
Car mass	$m_{1,109} = 1010$ kg	$m_{2,109} = 1120$ kg
Violence	$t_1 = \theta_{1,109}\alpha_{Vw}$	$t_2 = \theta_{2,109}\alpha_{Volvo} = \frac{m_{1,109}}{m_{2,109}}\theta_{1,109}\alpha_{Volvo}$
Probabilities from Kolmogorovs Eq.	$P_{j_{k,l}} = P_{1_{1,109}} = \frac{\lambda_0}{\lambda_1-\lambda_0}e^{-\lambda_0\theta_{1,109}\alpha_{Vw}} + \frac{\lambda_0}{\lambda_0-\lambda_1}e^{-\lambda_1\theta_{1,109}\alpha_{Vw}}$	$P_{j_{k,l}} = P_{0_{2,109}} = e^{-\lambda_0\frac{m_{1,109}}{m_{2,109}}\theta_{1,109}\alpha_{Volvo}}$

In order to estimate the parameters we use the Maximum Likelihood method. If we just studied crash number 109 the Likelihood would be:

$$L = P_{1_{1,109}}P_{0_{2,109}} = (\frac{\lambda_0}{\lambda_1-\lambda_0}e^{-\lambda_0\theta_{1,109}\alpha_{Vw}} + \frac{\lambda_0}{\lambda_0-\lambda_1}e^{-\lambda_1\theta_{1,109}\alpha_{Vw}})e^{-\lambda_0\frac{m_{1,109}}{m_{2,109}}\theta_{1,109}\alpha_{Volvo}}$$

In the full problem the Likelihood contains 2n factors and knowing which of the probabilities $P_0, ..., P_3$ to choose in every crash we are now able to calculate the Likelihood, L.

$$L = \prod_{k,l} P_{j_{k,l}}, k = 1, 2; l = 1, ..., n$$

The log-Likelihood is maximized in an estimation procedure, where the three different parameter vectors: the $\boldsymbol{\alpha}$, the $\boldsymbol{\theta}$ and the $\boldsymbol{\lambda}$ are estimated iteratively in three different steps. The estimation procedure works fine and since the project is still developping the results will be given in a forthcoming licenciate thesis.

7 References

Hägg A, Kamren B, v Koch M, Kullgren A, Lie A, Malmstedt B, Nygren Å , Tingwall C. (1992), "Folksam Car Model Safety Rating 1991-1992", FOLKSAM research.

Evans, L. (1994 a), "Driver Injury and Fatality Risk in Two-Car Crashes Versus Mass Ratio Inferred Using Newtonian Mechanics", Accident Analysis and Prevention, 26.

Evans, L. (1994 b), "Small Cars, Big Cars: What Is the Safety Difference?", Chance, Vol.7, No3.

5. SAFETY STATISTICS AND EVALUATION STUDIES

Chairperson: Siem Oppe

• **Measures of risk exposure in travel surveys.** FONTAINE Hélène, INRETS, Arcueil, France

• **Rear-end collisions and close following**. GLEDEC Mladen, Police Academy, Zagreb, Croatia

• **Differences between safe and unsafe zebra crossings in Switzerland.** EVERT Uwe, Swiss Council for Accident Prevention, Bern, Switzerland

• **Can weather-related traffic management and information improve safety?** KULMALA Risto, VTT, Esbo, Finland

• **CAI-System Utilization in the re-education of older driver's hazard perception.** OTA Hiro, Tohoku Inst. of Technology, Sendai, Japan

• **Lane keeping behaviour at profiled road markings on motorways : A before-and-after study.** VAN DER HORST Richard, DE VOS Alexander. TNO Human Factors Research Institute, Soesterberg, the Netherlands

• **Area wide illustration of car speeds.** JONSSON Thomas, EKMAN Lars, Dept of Traffic Planning and Engineering, Lund, Sweden

• **Evaluation of accident black-spot redevelopment – investigated at a sample of sites.** BERGER Wolfgang J, Institut für Verkehrswesen, Universität für Bodenkultur, Vienna, Austria

• **Quantitative Expert Judgement Models – A New Tool to Estimate the Effect of Countermeasures.** LEDEN Lars, Luleå University of Technology, Sweden. GÅRDER Per, University of Maine, USA. PULKKINEN Urho, VTT, Finland

Measures of risk exposure in travel surveys

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INRETS, Arcueil, FRANCE

Introduction

The quantitative analysis of road safety issues is based on study of the distribution of accidents and victims. But in order to target prevention efforts more accurately in this field, one has to identify the high-risk groups. This means comparing accident data with reference populations, i.e. with risk exposure data. Risk exposure may be represented by different indicators, such as population density, motorisation rate, number of driving licences, kilometres travelled and journey times. Reference indicators are generally selected with a specific objective in view, and the choice naturally affects the results of risk assessment, particularly the hierarchy of high-risk groups.

Data for injury accidents are taken from official statistics drawn up on the basis of Police reports. Exposure data are generally more difficult to obtain, hence the usefulness of transport studies such as those carried out by INSEE. Through trip notebook attributed to each vehicle, they provide substantial information about vehicles and their drivers, distances travelled, time spent driving and trip purpose.

The aim of this paper is to present the first analysis of these notebooks and to evaluate the changes in exposure characteristics and in accident involvement by comparing the data from the last two transport surveys carried out by INSEE and police accident data for the same periods. Two indicators are compared : accident per kilometres driven and accident per time driving.

Materials and methods

Data source and population studied

The purpose of the INSEE Transport survey was to produce a picture of the driving habits of households in France (Saglio et al., 1993). The results obtained may serve to measure structural changes since the previous survey in 1981-1982, in which the same definitions and principles were used.

The data collected from May 1993 to April 1994 concerned a sample population of 20 000 households surveyed in 8 waves. Each household was interviewed on two occasions, and between the two visits a car trip notebook was attributed at random to one vehicle in the household, to be completed by the driver(s) of the vehicle concerned over a 7-day period between the two visits. The driver had to note the characteristics of the trip at each stop, including the number of kilometres travelled and the time of day of the journey. All stops had to be mentioned, including those made to drop off or pick up passengers, but excluding stops at traffic lights, level crossings, etc.

The vehicles concerned by the notebook included private cars, small vehicles requiring no driving licence, camping cars or light utility vehicles (vans). For the purposes of our analysis we shall concentrate on private cars only.

Allowing for households which were not main places of residence and consequently were not included in the survey, and for non-responses, 9 515 log books were properly completed and described 197 003 journeys (Armoogum and Madre 1995). 8 783 of these notebooks were for private cars and described 183 450 journeys. To make sure the sample was genuinely representative, corrections were made in two stages (Armoogum, 1996) : correction of non-responses by post-stratification and correction of sampling errors by marginal adjustment. Weightings were calculated at different levels : household, person, log book.

A comparison of the results produced by the car notebooks with other sources of information, including daily journey descriptions, shows that the weekly notebook method can be used to observe 83 percent of annual mileage (Madre, 1996).

In the previous INSEE Transport survey, conducted from March 1981 to February 1982, a sample of 2 677 exploitable car notebooks describing 55 334 journeys was available (Fontaine and Saint-Saens, 1988).

Accident data used for the risk evaluation were drawn from the Road Traffic Injury Accident Analysis Bulletins (BAACs) compiled by the French police for each injury accident. We took accident data from the BAACs corresponding to the two Transport survey periods when cars where involved, i.e. 259 656 cars in 1981 and 167 854 cars in 1993-1994.

Method

Accident risk may be evaluated using various indicators which correspond to different objectives. The following are the most commonly used[1].

- The number of accidents or victims per year represents the risk to the community.

- The number of accidents or victims related to the number of inhabitants is often used in international comparisons of road safety, since it is the most readily available criterion. It is also used to analyse the risk associated with different types of accident, such as domestic accidents, aggressions, suicides, disease, etc. It is mainly a public health criterion. But strictly in the road safety field, it does not reveal any differences in the mobility patterns of the different populations concerned.

- The number of accidents or victims related to the number of vehicles gives a clearer idea of the mobility pattern, and also allows for the degree of motorisation in international comparisons, but it does not allow for the different types of vehicle use. It is often used, nevertheless, in particular by insurance companies, to calculate their premiums.

- The number of accidents or victims related to fuel consumption takes mobility into account, but does not provide differential results.

- The number of accidents or victims related to distance travelled, or time spent driving are indicators currently used in road safety. The time factor introduces the notion of mean journey speed. The relative risk obtained using this indicator amplifies the gaps between groups who drive at very different speeds : "fast" drivers represent a greater relative risk per unit of time than per unit of distance.

The analysis criteria adopted were driver age and sex. This information was available for those drivers who were members of the survey households, and they represent 98.6% of the journeys. These criteria were chosen initially because many studies have shown their effect on mobility and risk, both separately and together, and these variables link up with social attitudes in respect of risk (Cauzard, 1996; Biecheler et al., 1997).

The journeys were analysed according to distance travelled, time taken and mean journey speed. The mean speed includes stops at red lights, road junctions, level crossings, etc. It corresponds to the mean speed for all the kilometres travelled by the group concerned. While less informative than spot speed, which is a particularly important criterion in accidentology, but difficult to measure in the event of a collision, mean journey speed does reflect the behaviour of different groups of drivers. It must be remembered, however, that it is closely linked to the type of road network used. This geographical criterion was not revealed by the vehicle log books, since previous tests had demonstrated that the quality of this data collected over a one-week period was unsatisfactory.

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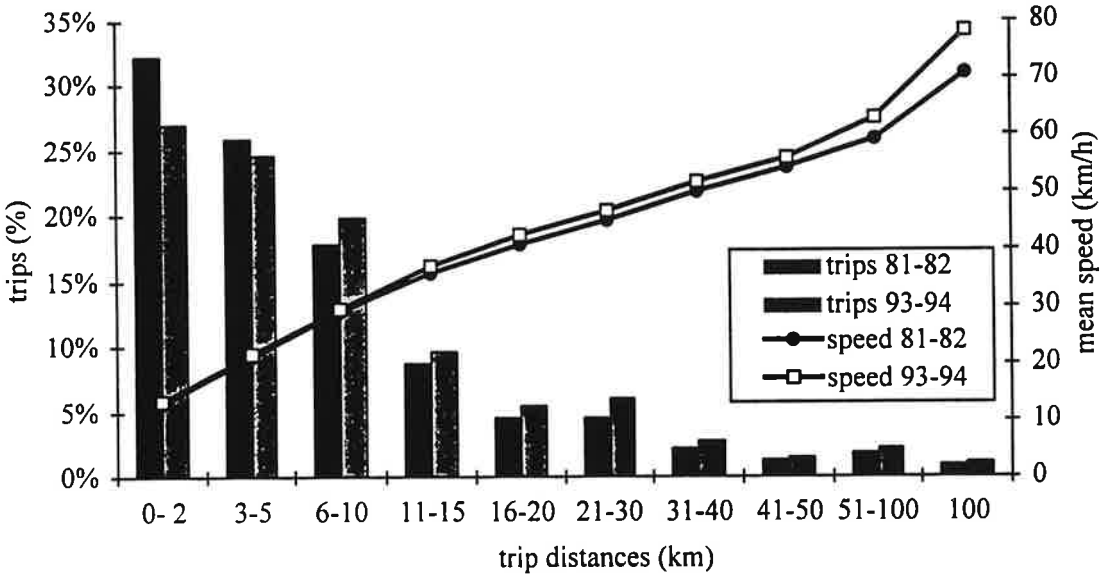
[1] We don't mentioned here exposure indicators based on non at fault drivers (induced exposure method)

Results

Exposure characteristics and changes

The average number of car journeys in the course of a week increased little between the two surveys (20.7 journeys per week in 1981-82 Vs 20.9 in 1993-94), i.e. three journeys per day. The average journey distance rose from 10.1 km to 11.8 km. Mean journey time also rose, but to a lesser degree, from 16.5 minutes in 1981-82 to 17.7 minutes in 1993-94. The distances travelled were covered at a higher speed, mean journey speed increasing by almost 10%, from 36.7 km/h to 40.1 km/h. While the proportion of short journeys was smaller in 1993-94 (figure 1), it was still high, with 52% of all car journeys no longer than 5 km, compared with 58% in 1981-82.

Figure 1 : Car journeys and mean speed according to distance travelled



Sources : Transport surveys 1981-1982 and 1993-1994

Average journey speed increases with the distance travelled. The reason for this is that the longer the journey, the smaller the part spent on urban roads, where the speed limit is lower. Note that for the same distance, the average speed increased between the two surveys. The greater increase in speed over longer journeys may be due to the development of the motorway network, particularly in periurban areas around major conurbations. This stagnation in the number of journeys, accompanied by an increase in the distances travelled and in speed, is found in the analysis of all types of transport (Orfeuil, 1996).

Female drivers accounted for 33.6% of the kilometres travelled in 1993-94 compared with 25.8% in 1981-82 (table 1). The share of journeys made by female drivers rose from 35% in 1981-82 to 44% in 1993-94. Women made up 43% of regular or occasional drivers

in 1993-94, up from 38% in 1981-82. The distances they travel are shorter than those travelled by men (9 km on average, compared with 13.8 km for men in 1993-94), and the average speed slower (35.8 km/h for women and 42.5 km/h for men). This no doubt reflects the higher proportion of urban driving done by women. This is borne out by the SOFRES panel survey on car driving (Fontaine and Gourlet, 1996), which showed that in 1994, 37% of the distance driven by female drivers was on urban roads and 17% on motorways, compared with 30% and 22% respectively for men.

Table 1 : exposure characteristics according to sex and age of driver

	kilometres travelled %		mean journey distance km		mean journey time mn		mean journey speed km/h	
Year	81-82	93-94	81-82	93-94	81-82	93-94	81-82	93-94
Sex								
men	74.2	66.4	11.6	13.8	18.0	19.5	38.6	42.5
women	25.8	33.6	7.3	9.0	13.6	15.2	32.4	35.8
Age								
< 20	1.9	1.4	10.9	12.1	16.8	19.2	39.1	37.7
20 à 24	11.4	8.6	10.3	12.5	16.4	17.7	37.5	42.3
25 à 34	31.5	25.8	9.5	11.3	15.5	16.7	36.7	40.6
35 à 49	33.0	37.9	10.1	11.5	16.5	17.2	36.7	40.1
50 à 64	18.4	19.8	10.9	12.7	17.9	19.2	36.4	39.6
³65	3.7	6.6	11.1	11.3	18.1	18.7	36.6	36.3
Together	100	100	10.1	11.8	16.5	17.7	36.7	40.1

Sources : Transport surveys 1981-1982 and 1993-1994

The ageing of the population and the fact that the number of years during which people drive has increased, enabling them to participate more in social life (Chich, 1991), have contributed to the larger share of elderly people in the driving population. The share of kilometres driven by drivers age 65 or over increased from 3.7% in 1981 to 6.6% in 1993. Mean journey length varies little with driver age, but the highest mean speeds were observed in the under-20 age group in 1981-82 and in the 20-24 age group in 1993-94. The lowest speeds were observed in the 65-and-over age group in 1993-94. This is also the age group for whom the percentage of urban mileage is lowest, probably because at this age there are no daily journeys to and from work (which often involve more urban driving) and because elderly people more often live in rural area. The lower mean journey speeds may therefore indicate a more "careful" style of driving among senior citizens.

The analysis also revealed a decrease in the share of mileage travelled by young drivers and an increase in that of drivers in the 35-49 age group. This may correspond to the time of life when many households buy themselves a home and move out of the city into the suburbs and also to the demographic changes.

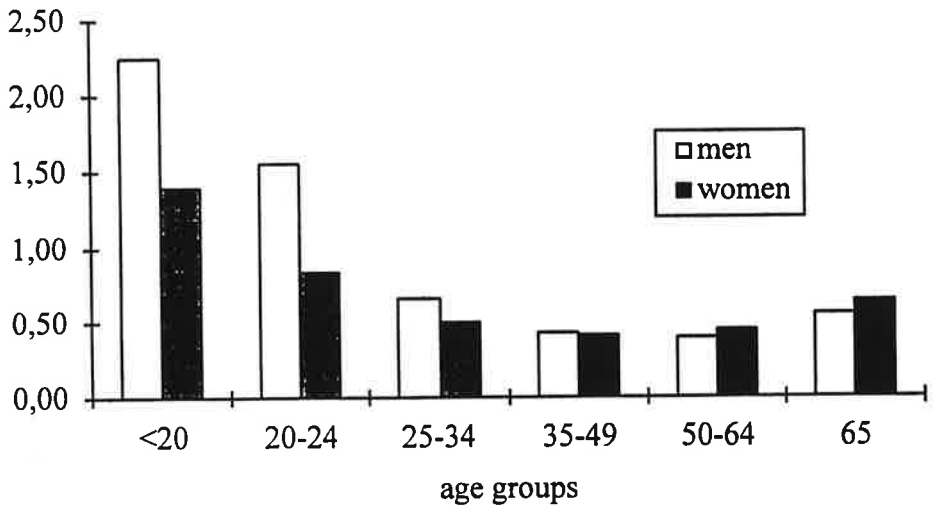
Risk evaluation

Between the periods analysed, mobility increased by 51%, with more cars on the road and drivers covering larger distances. At the same time, the number of injury accidents decreased. Consequently, the accident risk in terms of the number of accidents per kilometre travelled decreased. For the car driver population the risk decreased by 61%, from 1.5 injury accidents per million km travelled in 1981-82 to 0.6 injury accidents per million km travelled in 1993-94.

This decrease in risk, observed in numerous countries, confirms the frequently voiced hypothesis of a process of "collective learning" in motor vehicle driving (Brenac, 1989). Improvements to the inter-city motorway network may also have played a role in reducing the accident risk, insofar as motorways are among the safest roads, with a high traffic capacity. This could explain the increase in mobility in terms both of mean journey speed and of the number of vehicle-kilometres.

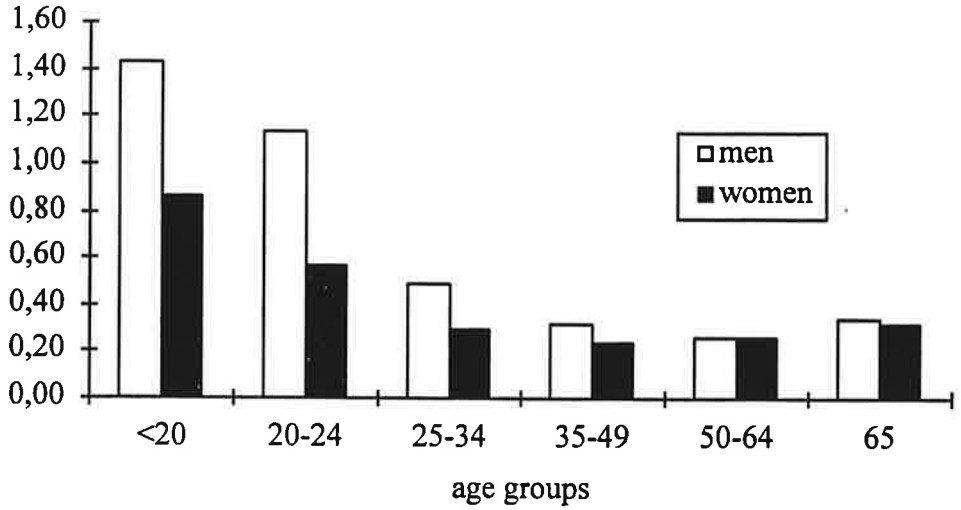
For the 1993-94 period, the rates per million kilometres driven (figure 2) exhibit the traditional curve with risk higher than average for the youngest and the oldest drivers, but the curve is much less marked in the case of women. Young men are at much greater risk than young women. This excess risk of young men is a finding commonly observed in road safety studies. Women age 65 and over, on the other hand, are at greater risk of injury accident involvement than men of the same age.

Figure 2 : accident rate per million driver-km



Sources : Transport surveys 1993-1994, BAAC 1993-1994

Figure 3 : accident rate per million driver-hours



Sources : Transport surveys 1993-1994, BAAC 1993-1994

When time spent driving is considered as exposure measure (figure 3), the highest risk groups are also drivers under 25 years old, particularly men. But whereas women age 65 and over are at greater risk over a given distance than men of their generation, when journey time is taken into account, women are at less risk than men for a given driving time whatever the age group. Similar results are found in Ontario (Chipman et al, 1993).This corresponds to their different journey speeds. The mean journey speed for women age 65 and over is 30.2 km/h, compared with 38 km/h for men in the same age group. This may be explained by the more urban nature of the journeys made by women, but also by the difference in their driving experience, elderly women often having started to drive later in life. This difference in the age at which men and women start to drive is tending to disappear (Fontaine and Hubert, 1997), as is the difference in mileage travelled. So it is possible to assume that the excess accident risk per km driven to elderly women compared with elderly men will decrease further.

The high-risk groups are the same in both cases : male drivers under 25 years of age. The behaviour of young men at the wheel is often blamed for the excess risk. It is also suggested that they drive in more difficult conditions (Massie and Campbell, 1993). Young drivers, particularly young men, drive more frequently at night : 19% of their mileage is done between 20.00h and 05.00h, whereas all drivers together travel 10% of their mileage during the same period of time (Fontaine and Hubert, 1997). For the same distance driven at night, they are more likely to be involved in accidents than any other driver category. Note that other factors, such as drinking, type of road and vehicle, number of vehicle occupants and type of journey, with peers or family, very certainly play a part.

Conclusion

This analysis of two transport surveys from the risk exposure standpoint, and comparison with accident figures for the corresponding periods, revealed a general decrease in the accident rates, which tends to confirm the hypothesis of a general improvement in driving standards.

The results show that male drivers under 25 years of age represent the highest risk group per distance driven and per time spent driving. But whereas women age 65 and over are at greater risk over a given distance than men of their generation, when time spent driving is taken into account, women are at less risk than men for a given driving time whatever the age group. This may be explained by the nature of the journeys made by women, but also by the difference in their driving experience, elderly women often having started to drive later in life. A comparison with the results of a previous travel survey carried out in 1981-82 shows that the difference in the age at which men and women start to drive is tending to disappear, as is the difference in distance travelled. Looking to the future, one can expect an increase in the proportion of elderly drivers on the roads, particularly women, accompanied by a decrease in the accident risk to these drivers. As a result, the relative risk to young drivers will appear higher.

Time and distance are not equivalent measures of exposure. Time spent driving seems to be a better indicator than distance driven insofar as the time drivers take to cover a given distance is the reflection of their perception of risk. However traffic conditions have also an influence on trip duration. Kilometres driven are not homogeneous as regards safety. Driving at night is more difficult than during the day and different driver groups drive in different conditions according to their trip purpose. When comparing the two indicators, the environment criterion must be checked so as not to confuse congested urban traffic situations and difficult driving conditions on small country roads.

Acknowledgements :

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References

ARMOOGUM J. (1996) : "La pondération de l'enquête transports et communications 1993-94", INSEE, note interne.

ARMOOGUM J., MADRE J.L. (1995) : "Correction de la non-réponse dans l'enquête Transport 1993-1994 : l'exemple des déplacements quotidiens", Entretiens Jacques Cartier

BIECHELER M.B., CAUZARD J.P., COMYN M. FONTAINE H. (1997) : "Synthèse mobilité, attitudes et accidents" Rapport de convention DRAST/INRETS

BRENAC T. (1989) : "Risque d'accident et caractéristiques des déplacements et des conducteurs" - Thèse de doctorat- 293p.

CAUZARD J.P. (1996) in SARTRE : "Les conducteurs européens et la sécurité routière" Edition Paradigme

CHICH Y. (1991) : "Sécurité routière et solidarité entre les âges" Les cahiers de l'assurance, Risques n°5

CHIPMAN M.L., MACGREGOR C.G., SMILEY A.M., LEE-GOSSELIN M. (1993) : "The role of exposure in comparisons of crash risk among different drivers and driving environments" Accident Analysis and Prevention Vol 25, n°2 pp. 207-211

FONTAINE H. et GOURLET Y. (1996). "Mobilité et accident - année 1994" Rapport de convention INRETS / DSCR

FONTAINE H., HUBERT J.P. (1997) : "Evolution de l'usage de l'automobile et du risque d'accident". RTS n°56 to be published.

FONTAINE H., SAINT-SAENS I. (1988) : "L'exposition au risque des conducteurs de véhicules légers", Rapport INRETS n°64

MADRE J.L. (1996) : "L'utilisation de l'automobile vue à travers différents instruments d'enquête", Conférence de l'Association pour la Statistique et ses Utilisations, Québec

MASSIE D., CAMPBELL K. (1993) : "Accident involvement rate by age and gender" - UMTRI Research Review Vol23, n°5 - University of Michigan Transportation Research Institute pp. 1-13

ORFEUIL J.P. (1996) : "La mobilité évolue, les problèmes et les solutions également" Colloque ADEME/INRETS

SAGLIO A., MAFFRE J., MARTIN P. (1993) : "Enquête Transports 1993-1994, instructions aux enquêteurs", INSEE

REAR-END COLLISIONS AND CLOSE FOLLOWING

Mladen Gledec

1. INTRODUCTION

Although, the consequences of the rear-end collisions are usually not so serious, this type of accidents presents a big problem on Croatian roads, due to its frequency; Almost one-fifth on the whole and one-third in urban areas, of all traffic accidents are just rear-ends.

The majority of them occur between 10a.m. and 6p.m., accordingly to the traffic flow frequency, and (by the way) in quite oposition to the presence of alcohol in drivers' blood; (Figure 1).

(Figure 1)

The majority of rear-end collisions in urban areas occur at crossroads - about two thirds. Almost half of them take place at signalised crossroads, which could be related to our findings previously found at the same kind of crossroads; (Gledec, 1996), i.e.

- the far most frequent type of accidents are rear-end collisions,
- amber light is very often too short (3 seconds on crossroads with speed of 60 km/h),
- accident risk is generally higher at the crossroads witout blinking green, than at those with blinking green.

In accordance with the above mentioned, it can be stated that the rear-end collisions are not quite "untied to area". But obviously, certain technical inconveniences are neither exclusive nor the main cause of their happening.

The origin of each accident is of course wrong behaviour. It is very logical to assume that the short time headway - as a wrong behaviour too - is playing an important role in causing rear-end accidents.

A recent Finish investigation by Rajalin and others (Rajalin, Hassel, Summala, 1997) found the relationship between the tailgating and increased number of traffic violations and also guessed "tailgating drivers" as more risky.

In our former preliminary investigation it has been found that the share of drivers following the predecessors on urban roads at time headway less than a second is between 10 and 39 %; (Gledec, 1997).

2. PROBLEM

To investigate and to state, at least at the level of indication, if the tailgating objectively indicates an increased accident risk; if there is any relationship between the time headway and accident risk and (serious) traffic violations.

3. WORKING METHOD

3.1. Data collection method

1. Field observation - recording of time headway

Field observation of vehicles' time headway have been performed on three different roads of urban road network, in all other similar conditions. All roads were dual carriageways, with speed limits 70 or 80 km/h.

The time headway of some vehicle was determined by using the stop watch in-built in "minispeed" equipment and its recording has been saved together with the video picture on the video tape, for further connecting of that time with the register plate of the vehicle. All that equipment is called "Travimo" and is installed in a civil car, almost quite unrecognisible to the drivers. So the recorded headways were the real ones in traffic flows.

As the stopping of the vehicles on the spot has not been done, the identity of driver was not established. Instead of that, the assumption that the vehicle's owner is the driver is established this way. Of course it could be rather doubtful asumption, but inevitable in given circumstances. Obviously, such assumption has certain influence on the validity of the results, which has to be kept in mind interpreting the final results.

Of interest here were the time headways less or equal of two seconds. Otherwise, it has not been regarded as a following. So, only such time headways, related with the corresponding registration number, have been included in the sample for further analysis. This way total sample of 297 time headways was collected. Stratified by the certain critical levels it was the following :

- < .8 seconds ..... 43 %,
- > .8 and <=1 second ..... 21 %,
- > 1 second ..... 36 %.

Such sample is the consequence of greater interest for shorter headways than for the longer ones, therefore it does not reflect the real distribution of time headways in traffic flow.

For the further analysis it was necessary to determine the identity of the driver. As the stopping of the vehicles on the spot was not carried out, drivers identification had to be done in some other way. Due to that certain part of sample is lacking for those vehicles

whose owners were not private persons. Because of that sample was further reduced; (to 210 cases with the very similar proportion concerning mentioned critical levels.)

2. Penalties data collection

The national data base of penalties and demerit points in traffic contains relevant data only for the last year - from the july of 1996. (Demerit system point was established here by the new Road Traffic Safety Act, stated on the beginning of July, 1996.) Unfortunatelly, there is no complete information in data base of all road traffic violations made by a certain driver and about the fines paid for them. Due to that, the idea of collection the data on the penalties has been abandoned. The mentioned data base contains only the total number of demerit points - representing of course only those more serious, as prescribed by the Act, (By the way, about 60 road traffic violations are followed by the demerit points).

Fortunatelly, during this investigation, re-checking of the driver - on the repeated driver exam - with at least 7 demerit points in a period of 24 months, has not started yet. Naimely, demerit points are deleted after successfully passed driver exam.

The key for data base retreiving was the " personal identification number" of an (assumed) driver, that has been read from the national vehicles' data base.

There were 25 drivers (12%) with the demerit points, in the span from 1 to 4.

3. Accidents data collection

The national data base of traffic accidents and their participants, established in the present form, covers the time period of only the last two and half years - beginning with 1995. This data base retrieved by the unique personal number of the driver. For the reasons of simplicity, only the data on the role of participant in accident is consulted. All other data (type of accident, consequences, ...) were omitted. This way it was found out how many accidents each driver have had in the last two and half years.

There were 40 drivers (19%) with accidents; one or two.

3.2. Data processing method

Statistical analysis of all collected data has been performed by using the STATGRAPH package. For making the graphs of final results the same programme has been used, as well as the programme of HG.

4. RESULTS

As stated earlier, the identity of the driver in the vehicle owned by a non-private person had not been stated so that these data had been omitted from the sample in further

processing. But it could have had possible influence on the sample pattern if, for instance, the drivers of the non-private vehicles had operated the vehicles in a different way.

The comparison of these two groups of drivers did not show significant differences in time headways. Therefore, we can come to the conclusion that the drivers are similar to each other; (T-value was 1,308). In other words, the sample reduced this way did not changed its pattern.

The distribution of all headways is shown in Figure 2. It has to be stressed that it is not the real distribution of time headway in traffic flow, because the shorter headways were of primary interest.

(Figure 2)

Figure 3 shows the distribution of the shortest headway - up to 1 second. As it can be seen, the most frequent ones are the headways of 0.6 seconds. There are even those of only 0.2, as it can also be seen.

The possible relationship between the headways and traffic accidents on one hand, and number of demerit points on the other was sought by the regression analysis. The results did not indicate any relationship between the headways and the indicators of danger, which was not surprising because of the small values and demerit points, and especially the accidents.

But it does not mean that some particular tendencies are quite impossible (that might be relevant if the sample would be greater). In that sense the distributions of the headways for particular levels of the dependent variables have been compared. Namely, it was of interest to see whether the headway distributions for the drivers

- without accidents,
- with one accident, and
- with two accidents,

were similar or different in certain elements. If the headway distribution for drivers without accidents is similar to those with accidents, the time headway could hardly be indicator of the real danger, and vice versa.

The concordance of headway distributions for different levels of demerit points - from 0 to 4 - was also analysed.

Figure 3 shows the shortest headway distributions for different number of accidents. Although all of them are rather similar, it seems that certain differences do exist. In the group of drivers without accidents there are quite a lot of them with the headway of one second. In the group of drivers with one accident, the same headway is much less present, and in the group of two accidents there is almost none.

(Figure 3)

Drivers with very short headway of 0.3 seconds are exclusively those with (one) accident. The drivers with two accidents, though rare (only 2 % of all and 13 % in group of "accidental" drivers) are exclusively those with the headways from 0.5 to 0.7 seconds).

When all the headways are being observed simultaneously, the picture is not changed, except for the fact that in the group of drivers with one accident the most frequent are those with the headway of 1.3 seconds that is surprising; (figure 4).

(Figure 4)

Figure 5 presents the headway distributions for the different levels of demerit points - from 0 to 4.

(Figure 5)

The drivers with headway of 1.6 seconds are present in the groups with demerit points with much less proportion. It has to be noted that in the groups of drivers with 3 and 4 demerit points are only the drivers with the shortest headways - 0.3 - 0.6 seconds.

It seems that the biggest discordance exists in the shortest headways - less than a second; (figure 6). The drivers without demerit points quite differ from those with points. In the group without points there are plenty of very short headways, but also those with the proper headways - of 0.9 and 1 second. In the group of drivers with one point there is the dominance of shorter headways; in the groups of drivers with 3 or 4 points that is even more present. In the group of 2 points more present are those with proper headways.

(Figure 6)

The possible relationship between the number of demerit points and traffic accidents was sought by regression analysis. None relevant relationship has not been found. In accordance with those results, it could hardly be said that the number of demerit points is valuable indicator of driver's danger. Of course, all the previously mentioned limitations must be kept in mind here.

5. DISCUSSION

Several important things must be taken into account when discussing the results shown before. First, data sample was rather small and limited and uneven relating to the different levels of the variable of primary concern. Further, it was assumed that the driver and vehicle's owner are the same person, which is of course false assumption in a certain way.

Also, the short period of time of accidents happening that was taken into consideration was of certain influence. Primary dependent variable had to be the accident risk - the number of accidents related to the driver's exposure to risk. Since the data on the exposure are doubtful in general - and especially here, where identity of the driver was

not exactly determined - it was further assumed that all the drivers - or at least the drivers at the same level of time headway - had the similar exposure to risk.

Also, all of the accidents for the certain driver were analysed, and not only the rear-end collisions, despite the fact that rear-ends are of primary interest. Otherwise, the sample of data would have been diminished additionally, and so quite improper for any analysis.

With regard to all of the mentioned limitations and assumptions, the reached results can only be the indication of and orientation for the considered issue. That investigation should accordingly be regarded as the preliminary one.

Having all this mind, it is even surprising that the previous results are as they are - rather consistent and balanced. For the time being they are showing mostly that tailgating does not indicate greater inclusion in traffic accidents or increased accident risk. It seems that tailgating indicates in a way a greater proneness to more serious traffic violations. If so, the question arises on the nature of relationship between the serious traffic violations and accident risk.

Anyway, there are more questions than answers, showing at least that the further investigations in this field have to be done, more comprehensive and more precise.

6. CONCLUSION

On the basis of the results of this preliminary analysis on time headways and its indicativeness for accident risk it could hardly be said that short time headway is relevant for happening of traffic accidents and increased accident risk. Anyway, much more investigations in that field is needed for more resolute conclusions.

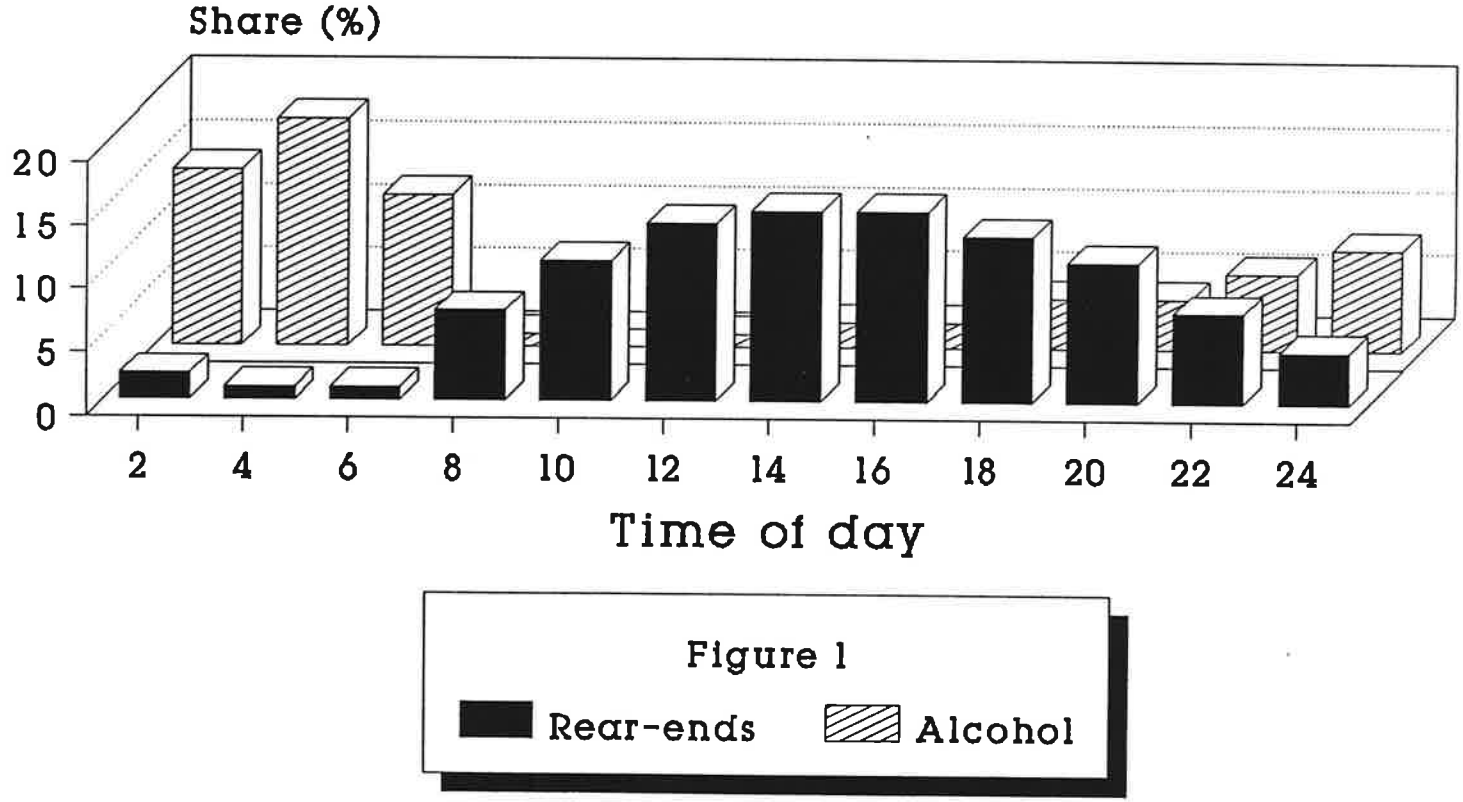
7. REFERENCES

1. Gledec, M. : Behaviour of Drivers at the Crossroads Regulated With Traffic Lights, With and Without Blinking Green Before the Yellow Lights Turns On - Croatian Experience, 8-th IFAC Symposium on Transportation Systems '97, Chania, Greece, Proceedings, Volume III. (16-18. 6. 1997)

2. Rajalin, S., Hassel, S.O. and H. Summala : Close-following Drivers on Two-lane Highways, Accident Analysis and Prevention, (will be published in 1997).

3. Gledec, M.: Rear-end Collisions and Following Distances, Police and Security, Zagreb, Croatia, 3, 1997 (in Croatian).

REAR-END COLLISIONS
AND PRESENCE OF ALCOHOL IN THEM
(TIME DISTRIBUTION)



CROATIA, 1996.

Figure 2 HEADWAYS DISTRIBUTION
(HEADWAYS <= 2 SECONDS)

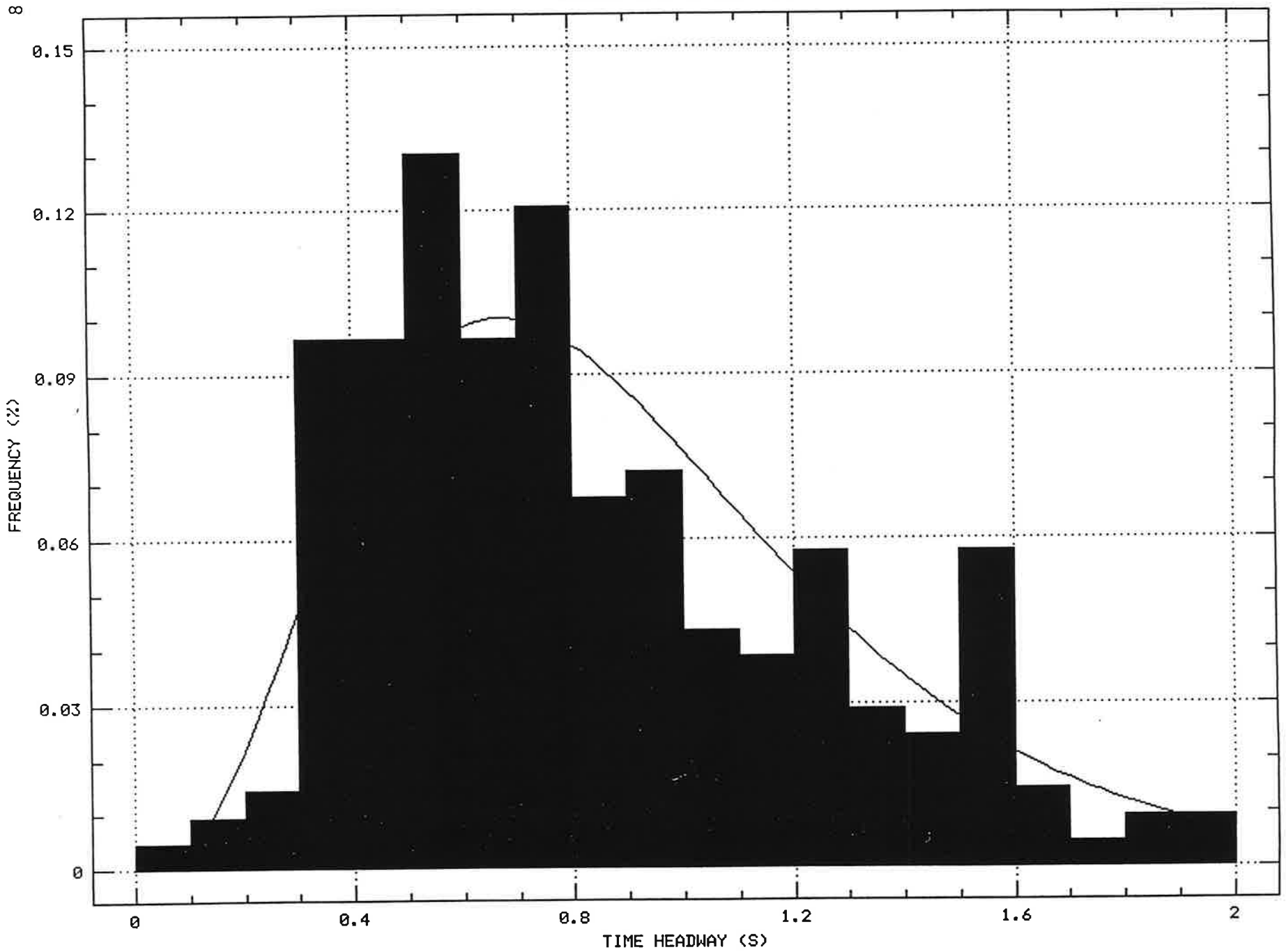


Figure 3 HEADWAYS AND ACCIDENTS
(TIME HEADWAYS <= 1 SECOND)

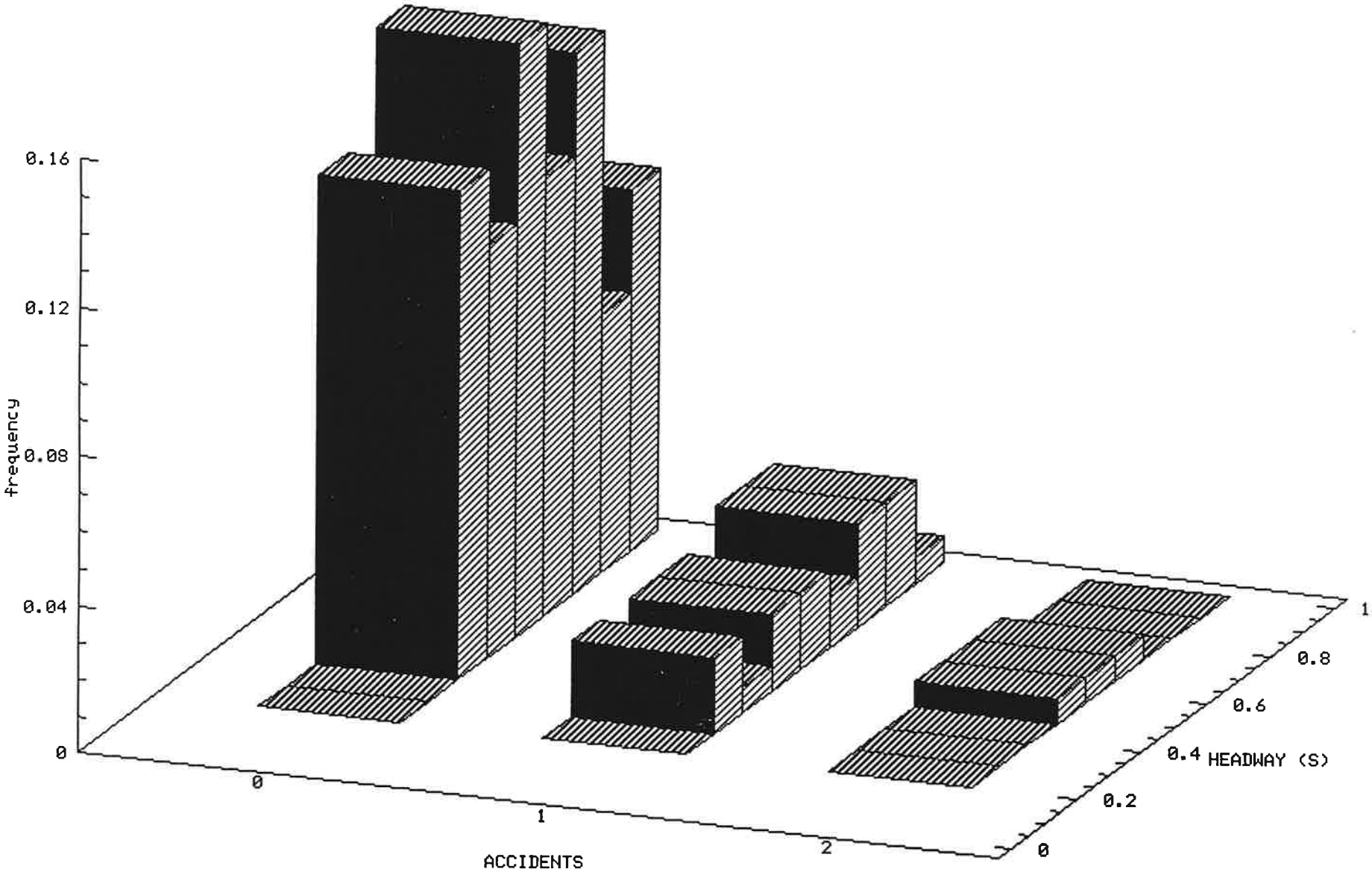


Figure 4 HEADWAYS AND ACCIDENTS
(TIME HEADWAYS <= 2 SECONDS)

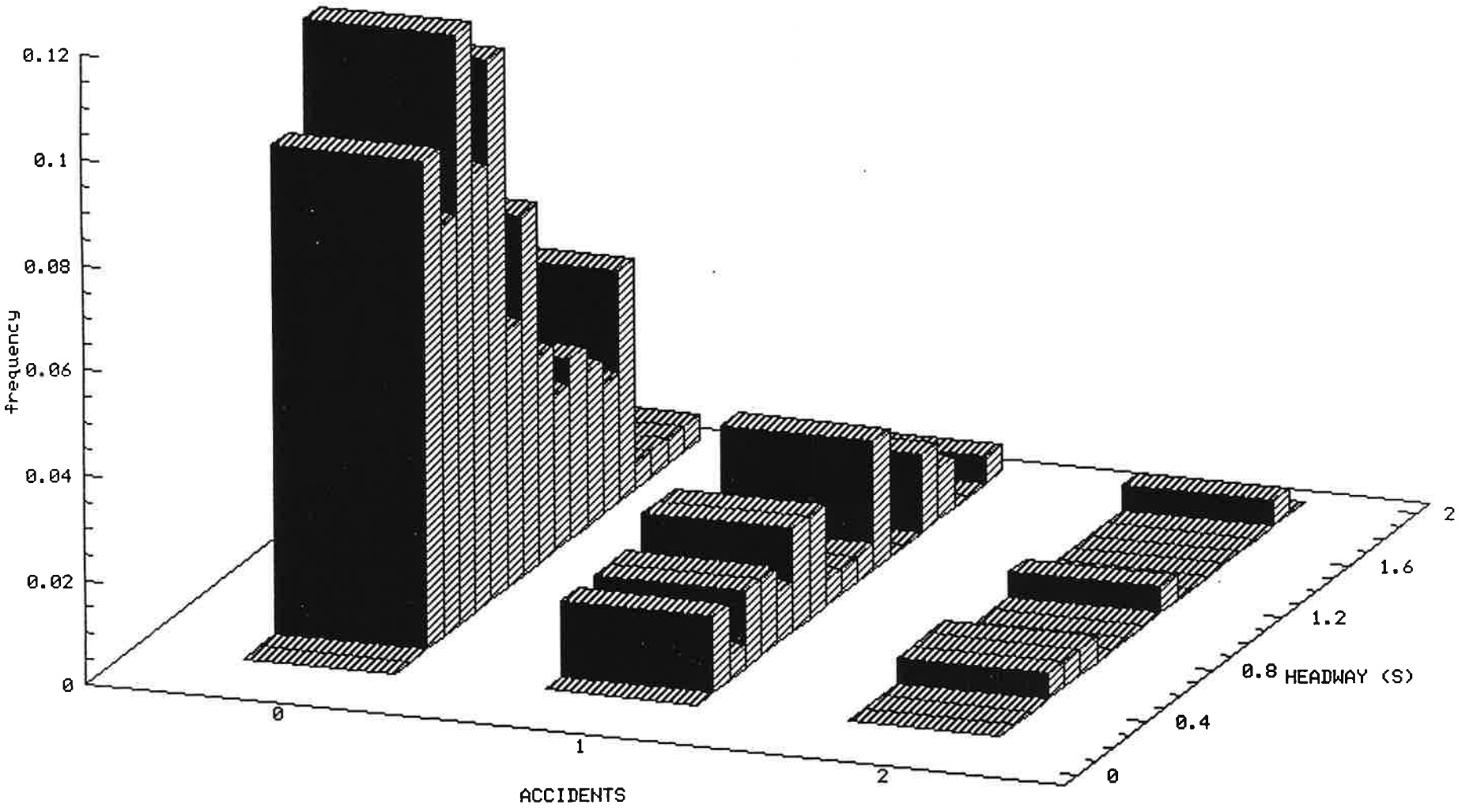


Figure 5 HEADWAYS AND DEMERIT POINTS
(TIME HEADWAYS <= 2 SECONDS)

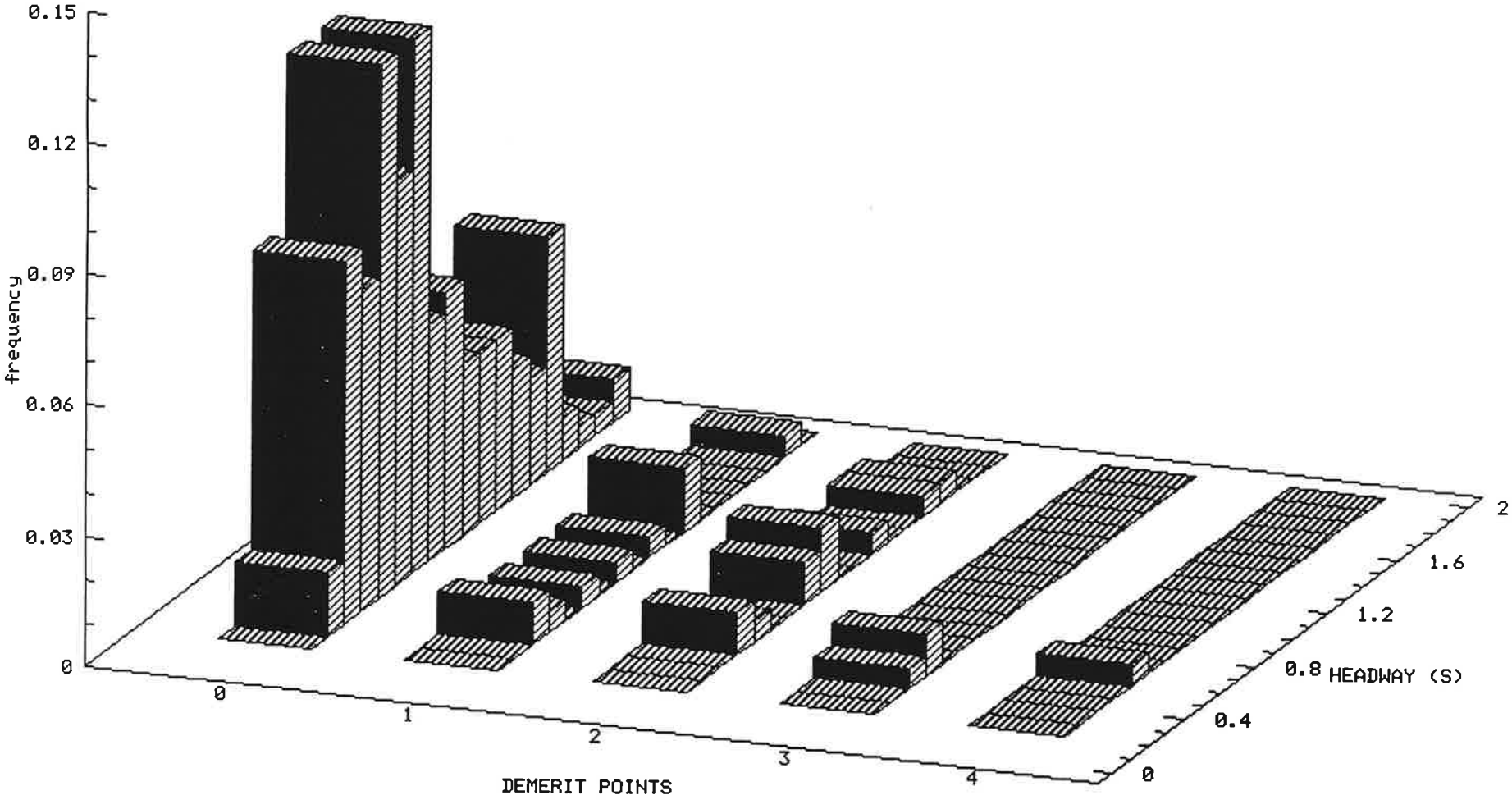
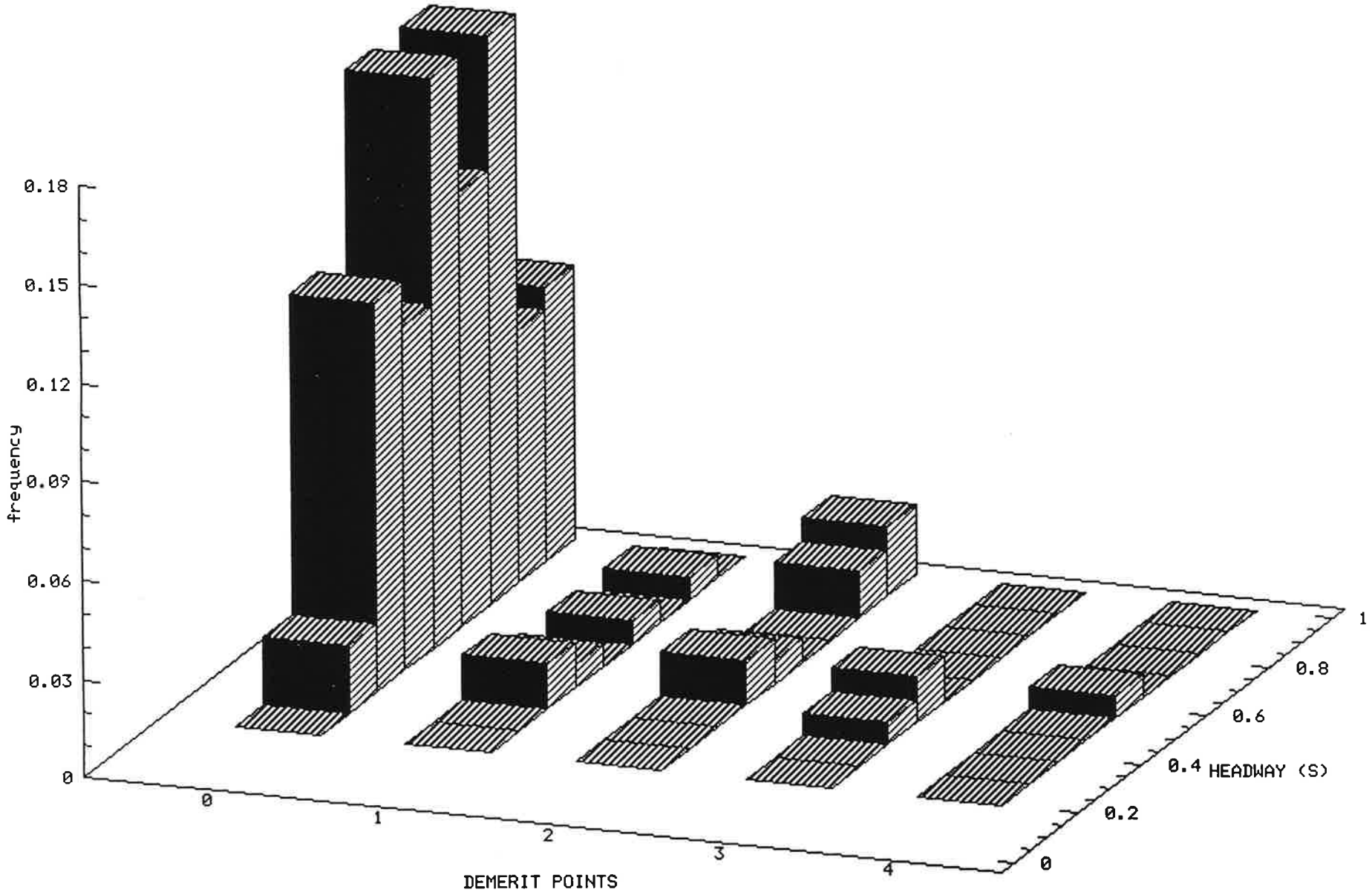


Figure 6 HEADWAYS AND DEMERIT POINTS
(TIME HEADWAYS <= 1 SECOND)



Differences Between Safe and Unsafe Zebra Crossings in Switzerland

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Introduction

In Switzerland between 33 % and 40 % of all injured pedestrians are involved in accidents at pedestrian crossings that are not controlled by crossing lights. The proportion of fatalities is a little lower, i.e. the injuries are somewhat less severe. The rather large proportion of victims at a location designed for pedestrian safety was the starting point of our investigation. The aim of the study was to find differences regarding design/layout and operation between safe and unsafe pedestrian crossings in order to be able to give advice as to their improvement.

Selection of crossings to be evaluated

At a first step safe and unsafe pedestrian crossings had to be identified. Communities all over Switzerland were asked to report pedestrian crossings with an occurrence of 2 or more accidents with injured victims within the last 2 years. The criterion chosen seems to be rather soft, but locations with a higher incidence of accidents are considered black spots which are usually subject to rapid changes. Nonetheless we had 1 crossing with 5 injury accidents in the last two years. 110 crossings were reported from german- and french-speaking cantons. Out of these a 50 % random sample was selected for participation in the study. Due to organizational reasons, observations could only be made at 45 of the 55 selected pedestrian crossings.
The next adjacent pedestrian crossing on the same road was chosen as a control, presuming no accidents had occurred there within the last two years. This eliminated the confounding variable of average daily traffic which, of course, was identical for the experimental and control group.

Selection of dependent variables

Three types of dependent variables were analyzed. First of all, the variables concerning the design of the pedestrian crossing, second, variables of operation and third, variables relating to the accidents that had occurred. The variables are listed in the following three tables.

Design variables
Lighting
Road Width
Pedestrian Traffic Island
Total Number of Traffic Lanes
Placement of Pedestrian Crossing Within the Road Network
Vehicle Accessibility to Pedestrian Waiting Areas
Visibility
Recognition of Signs
Traffic Sign "Location of a Pedestrian Crossing"

Operating variables
Amount of Pedestrians
Motorized Traffic Speed

Accident Variables
Date
Day of Week
Time
Lighting Conditions
State of Road
Weather
Conflicting Object
Side of Road From Which the Pedestrian Departs
Side from Which the Car is Coming
Number of People Injured
Number of People Killed

Data collection

Data collection differed depending on the sources of data used. The design variables were observed by a traffic engineer who conducted the measurements at the scene. The operating variables were observed by students who counted pedestrians crossing the streets and who measured the speeds of cars every five minutes. The speed observations were done in such a way that the drivers could hardly see the speed guns until after having passed the observer. The observations were conducted from 7 o'clock in the morning to 7 o'clock in the evening. For all accidents that had happened at the selected sites the accident protocols (that had to be filled out by the police) were requested from the communities. Relevant information from the protocols was transferred into another form and then entered into the data set.

Results

Design Variables

- Traffic Islands were found significantly more frequently at the safe than at the unsafe crossings: 45% vs. 30% (Chi-Square=5.05, df=1, p=.025).
- At safe pedestrian crossings an unhindered view to the left (more than 100m) could be found more frequently than at unsafe crossings (62% vs. 69%, Chi-Square=6.48, df=1, p=.011).
- The results concerning the traffic sign "Location of a pedestrian crossing" are twofold. A significant difference between safe and unsafe pedestrian crossings could be found concerning the presence of the sign. At 57 % of the unsafe and at 63 % of the safe crossings the sign was present (Chi-Square = 29.5, df=1, p=.000). Moreover the visibility of the sign differed among the crossings. The sign could be seen from a distance of more than 100 m in 42% of the unsafe and 54% of the safe crossings.
- At unsafe pedestrian crossings the proportion of roads with more than two lanes was higher than at the safe crossings (27% vs. 18%, Chi-Square=14.9, df=6, p=.021). With regard to the other design/layout variables no significant differences were found.

Operating Variables

- The amount of pedestrians that were observed at the safe and unsafe pedestrian crossings was quite different: there were almost twice as many pedestrians at the unsafe crossings. For example: in the six hours with the highest number of crossings maneuvers 533 vs. 294 pedestrians were observed. This difference is highly significant (t=2.77, df=41, p=.008).
- Small but highly significant differences were also found between the speeds driven at the crossings. At the safe crossings the speed was 44 km/h vs. 41 km/h at the unsafe pedestrian crossings (t=-15.3, df=8260, p=.000).

Accident Variables

An attempt was made to relate the accident variables, i.e. the characteristics of the accidents, to certain design and operating features. Only one significant result could be found. When the road is dry almost twice as many accidents occurred on roads with more than two lanes than on roads with only two lanes (1.0 vs. 1.8 accidents, F=8.65, df=1, p=.005).

Conclusions

The present study indicated that differences exist in the design and operation of safe and unsafe zebra crossings. It should be noted that part of the differences in the number of accidents may be accounted for by the number of pedestrians crossing, i.e. by higher exposure. Still, even if the number of pedestrians was only half of that found at the unsafe crossings the number of accidents would still be higher than at the safe crossings. Thus, the classification of safe and unsafe still seems to be justified.

The lower speed at the unsafe pedestrian crossings probably reflect the behaviors of the drivers who, upon reaching a frequently used crossing, might somewhat lower their speeds in order to be able to react rapidly if necessary. It must be stressed that only cars where measured which were not hindered by other cars or pedestrians, i.e. the drivers could freely choose their speeds.

The results warrant certain changes in the design (and the norms concerning the design) of pedestrian crossings:

- No zebra crossings should be constructed over roads with more than two lanes.
- Traffic islands should be used whenever possible, even if some construction work has to be done.
- Pedestrians should have an unhindered view of a 100 m and more towards the left.
- The sign "Location of a pedestrian crossing" should be made obligatory and visible from a distance of more than 100 m.

A more general conclusion of this research project is that the norms that are being used are often not based on empirical evidence. As an example I would like to present the recommendations regarding minimal sight distances depending on the speed driven.

Minimal Sight Distances in Depending on the Speed Driven (V85)

V85-Speed (km/h)	Swiss Recommendation	New Zealand Recommendation
40	40	55
50	55	75
60	70	95
70	90	120
80	120	150

The Swiss recommendations were derived from the usual formulae. For safety reasons the derived values were doubled. As we can see from the differences in accidents, the values in the norms do not seem to suffice. My opinion is that the attention of the drivers was sufficient most of the time, but that the recommendations are too conservative under extreme conditions.

I would like to conclude my presentation encouraging you to check the norms with regard to their safety effects. The norms are not an end in itself and not sufficiently justified by a mere expert judgements without an empirical basis.

Can weather-related traffic management and information improve safety?

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1. Introduction

Road safety has steadily improved in Finland during the last years except for accidents on wintry road conditions. The number of these accidents has remained the same during the last years. Ca. 25% of all fatal accidents occur on icy or snowy road surfaces, and an additional 15% in other adverse weather conditions.

The primary measure used to decrease accidents on icy and snowy roads is to improve the road surface conditions with the help of road maintenance actions (de-icing with salt, sanding, snow removal, etc.). Winter road maintenance usually applies the following procedure:

1. the personnel at the Road Weather Monitoring Centre (RWMC) starts to suspect of slipperiness on the basis of data from automatic weather monitoring stations, CCTV cameras or reports from neighbouring road offices
2. the on-duty person at the local road office is informed
3. the local road office checks the slipperiness on location
4. the local road office reports possible slipperiness and calls for maintenance actions
5. the road maintenance unit acts accordingly

This procedure is quite efficient but takes time. Time is critical as the accident risk in the hour preceding maintenance actions is estimated to be 12 times as high as it was twelve hours earlier (Öberg 1993). Hence, the Finnish National Road Administration (Finnra) especially aims to improve safety in the period from first indication at the RWMC to the start of maintenance actions on the road section by warning road users about the possible slipperiness.

The warning of road users should be useful as on slippery road surfaces only 14% of drivers estimate the road to be slippery, while more than 50% regarded the friction to be quite normal (Heinijoki 1994).

On average, drivers adapt their speeds to the road surface conditions. The mean speed on a slippery road surface is ca. 4 km/h lower than in good winter conditions, and the standard deviation of speeds is also lower due. This is due to the fact that the highest speeds decrease especially much compared to other speeds (Saastamoinen 1993). Theoretical calculations concerning stopping distances, however, have proven this adaptation to be insufficient in

order to compensate for the reduced friction (Heinijoki 1994). In addition, Roine (1993) showed that in slippery conditions drivers have much smaller safety margins at curves than in good conditions.

Road surface conditions also affect headways. In south-western Finland, the percentage of headways shorter than 1.5 seconds is ca. 25% in slippery conditions compared to 39% in good winter conditions (Saastamoinen 1993).

The following chapters present the results of mainly Finnish studies on the use of traffic information and management systems in solving the afore-mentioned problems.

2. Importance and use of information

A telephone interview of Finnish car drivers was undertaken in 1996 to investigate user requirements for various traffic information systems (Penttinen, *et al.*, 1997). According to the study, The most popular sources of information were variable message signs (VMS), television, newspaper and radio. Road maps, road work maps, text television, RDS-TMC and information monitors at service stations were also considered important. The drivers showed least interest in Internet, GSM messages, as well as individual telephone service and fax service provided by the road administration. All information sources were estimated to be more important for infrequent than frequent trips. There were little differences between driver categories (i.e. sex, age, driving experience and area of residence). Nevertheless, the most experienced drivers wished to receive more on-the-road information (variable message signs, RDS-TMC and GSM messages). Men were more interested in RDS-TMC and GSM than women. Young drivers were more interested in GSM and CD-ROM-map than the others.

The drivers were asked to rate the importance of various information types. Weather and road surface information was regarded as the most important information type. Ca. 40% of the drivers regarded weather-related information important for their daily recurrent trips, and more than 50% for more seldomly made trips. In the wintertime, 42% of drivers obtained weather-related information for their daily recurrent trips, and even 59% for the more seldom trips (Penttinen, *et al.*, 1997).

Of the various weather-related information items, the drivers regarded most important the ones about current slipperiness, iciness, slush or snowing. The items ranked next were road surface forecasts, winter maintenance action reports, and fog. The least important items were road surface and air temperatures as well as rain (Penttinen, *et al.*, 1997).

The drivers reported that weather-related information mostly affects their manner of driving. Information affects to a smaller extent the time reserved for the trip and the choice of departure time. The least effect was reported for route and mode choice as well as whether the trip should be made at all (Penttinen, *et al.*, 1997).

This does not mean that the least effects were very small. For example, 16 - 18% of the drivers reported weather-related information to affect their decision about whether to make

the trip or not. Interestingly but not surprisingly, elderly drivers reported more than twice as frequently as other drivers that their trip-making decisions are affected by weather-related information (Penttinen, *et al.*, 1997).

3. Information systems

Knowledge of the possible slipperiness or other weather problems is important to the drivers. Primarily, there are two types of technologies that can assist the drivers to acquire that knowledge. The driver can obtain the information 1) directly from his/her vehicle's own sensors or 2) from the road authority's in-vehicle or roadside sensors via an traffic information service.

The first case would seem to be better as it gives real-time information of the situation to the driver. Unfortunately a sufficiently reliable sensor system capable of continuous friction measurement is not yet available in the mass market. Various slip avoidance and ABS systems enable friction estimation, but usually in situations involving heavy braking, i.e. too late (Juhala 1994).

Hence, the dissemination of the road authority's weather information is currently the main instrument for increasing the drivers' knowledge of the weather conditions. The use of various information dissemination means is necessary in order to provide the information to as many road users as possible.

In Finland, pre-trip information services use radio, television, text-TV, telephone, internet, and information kiosks as communication means.

On-trip road weather information can also be distributed via a number of traffic and travel information services, e.g. RDS-TMC and GSM based services. In the case of local weather problems, the PROMISE GMS service utilises the Cell Broadcasting facility in GSM to broadcast weather warnings to only those cells in the cellular network suffering from the weather problem. One cell covers ca. 10 km of road length in the rural areas of Finland.

At points with exceptional road weather conditions and frequent weather-related problems, the use of VMS (Variable Message Signs) is feasible. In Finland, Finnra has initiated a systematic evaluation of the use of VMS in solving weather-related problems, starting with the comprehension of messages, development of the VMS control systems and algorithms, and ending with actual impact evaluation of pilot implementations.

Hirvenoja (1994) studied the comprehension of various weather messages with the help of interviews. A large majority of drivers understood the "slippery road" pictogram including a snow flake symbol (Figure 1) correctly, and the pictogram had also the highest user acceptance for implementation. The drivers had great difficulties in interpreting correctly friction coefficients, whereas headway recommendations such as in Figure 2 were understood quite well (Hirvenoja, 1994).



Figure 1. Slippery road VMS.



Figure 2. Headway recommendation.

The slippery road VMS display (on/off) as well as the following distance recommendation also depends on the road surface condition classification by the RWMC. In addition, the headway recommendation depends on vehicle type and the speed of the vehicle. The following distance recommendation was actually the estimated stopping distance with an additional one second reaction time, and 1.5 seconds for lorries taking into account the brake delays (Rämä, *et al.*, 1996).

Rämä, *et al.* (1996) studied the effects of slippery road warning VMS (as in Figure 1) on driving behaviour. The signs were found to decrease driving mean speeds by 1 - 2 km/h, and the effects could be detected as far as 14 km after the sign.

The dynamic headway recommendation also decreased driving speeds by ca. 1 km/h, and in addition decreased the percentage of short headways by ca. 25%. More than 80% of the drivers understood the VMS messages correctly (Rämä, *et al.*, 1996) after the addition of a supplemental sign with the text "recommendation" below the sign. The effects of the sign on short headways were about half higher before the additional sign was installed, indicating that some drivers might interpret the sign to be linked with automatic police surveillance.

In addition to the effects on speed and headway, the signs might have other impacts on driver behaviour. Consequently, a combined roadside and telephone interview was undertaken to investigate other potential responses to these signs (Luoma, *et al.*, 1997).

The results suggested that these variable message signs have many other impacts than can be measured in terms of speed and headway. The most essential effects deal with the direction of attention to find cues showing potential hazards, testing the slipperiness, and careful passing behaviour. On the other hand, the results suggest that the driving speed and headway are also the most essential variables which many other variables correlate with (Luoma, *et al.*, 1997).

The automatic fog-warning system on the M25 motorways in England displays the "Fog" legend on roadside matrix signals. The assessment of this system showed that the net mean vehicle speed reduction was ca. 3 km/h, when the signals were switched on as a result of the formation of fog (Cooper and Sawyer, 1993).

4. Traffic management and control systems

A German study (Balz & Zhu 1994) on the effects of a fog warning system employing VMS and variable speed limits found the accidents after the implementation of the system to decrease by 30% on the study section. Accidents in fog had decreased 85%. The number of accidents had also decreased on other motor ways in the same area by 10% in the same period, while the number of accidents in fog had decreased by 64%. Hence, the effect of the weather warning system was a ca. 20% reduction in the number of accidents. The speeds had decreased by ca. 10%.

A Dutch fog warning system included text warning ("fog") and dynamic speed limit VMS signs on a motorway. The evaluation of this system showed a positive effect on driving behaviour. The system reduced speeds in fog by 8 to 10 km/h, although in extremely dense fog (visibility less than 35 m), the system had an adverse effect on speed. This was due to the too high lowest possible speed limit display in the VMS (60 km/h). A more uniform speed behaviour was obtained on the entire carriageway due to the introduction of the system. All effects pointed towards safer behaviour and reduced accident risks (Hogema, *et al.*, 1996).

A Finnish weather controlled motorway section is equipped with variable speed limit signs and warning VMS (Pilli-Sihvola, 1996). The effects of the system were evaluated by Rämä (1997). In the wintertime, the change from 100 km/h to 80 km/h decreased the mean speed of cars outside platoons by 3.4 km/h, in addition to the average mean speed reduction of 6.3 km/h caused by the adverse road surface conditions. The corresponding effect was 2.5 km/h for all cars in addition to the effect of the adverse conditions (-6.3 km/h). If there was no rain or the rain was insignificant, the effect was ca. 2 km/h more i.e. 4.6 km/h. The proportion of these conditions was approximately 95% of all "adverse" conditions. When the road condition was such that the slippery road warning was displayed the speed reduction was 1.8 km/h for cars outside platoons in addition to the -9.3 km/h "weather effect" (Rämä 1997).

In the summertime, the change from 120 km/h to 100 km/h decreased the mean speed of cars outside platoons by 5.2 km/h, and the change from 120 km/h to 80 km/h by 8 km/h in addition to the average decrease in the mean speed caused by the adverse conditions (-2.0 km/h and -6.1 km/h, respectively). (Rämä 1997)

A very interesting result deals with the speed distributions. The lower speed limits on the test section decreased especially the highest speeds, and consequently the speed variance was reduced. In the control sections, however, adverse road conditions resulted in increased

speed variance despite the mean speed reduction. A more detailed analysis of the distributions showed that this was caused by the fact that the highest speeds almost did not decrease at all whereas the lowest speeds decreased considerably. The most cautious of the drivers are most affected by the conditions, but some drivers are not affected at all. The latter perhaps regard the speed limit (permanent on the control section) as a "social norm" or speed recommendation valid in all conditions. (Rämä 1997)

The comparison of the displayed speed limit and manual observations of the weather and road conditions indicated that too high speed limits were applied in 26% of the cases. The speed limits displayed were seldom too low. There were even rare cases, when the speeds on the control section were lower than on the study section (very snowy winter conditions, speed limits displayed on test section 80 km/h). The speed limit of 80 km/h was evidently too high for these exceptional conditions. (Rämä 1997)

Currently, dynamic speed adaptation systems are being developed for cars, e.g. in Sweden. These systems employ a speed limiter which automatically sets the maximum speed according to the static speed limit and the prevailing dynamic conditions. This could be developed to automatically react to the road weather conditions. When approaching a curve on a slippery road, e.g., the system would set the maximum speed so low that the driver should be able to drive safely along the road through the curve without losing control of the vehicle. Such a system would require heavy investments in roadside equipment, although a less ambitious system based on satellite positioning, digital maps and dynamic wireless information services could be a feasible solution. The system would be very effective in improving safety. User acceptance problems can be expected, although the first experiments with test vehicles employing a speed limiting device have indicated a surprisingly high user acceptance (Almquist and Nygård, 1997).

5. Can the systems improve safety?

Knowledge about the current weather and road surface conditions is clearly not enough to reduce the accident risks in adverse conditions to their level in good conditions despite the optimistic expectations of those who plan and implement weather-related information systems. Accident risks on adverse conditions are many times as high as in good conditions, but the speed effects of information systems are only in the magnitude of 1 - 3 km/h. This speed reduction corresponds to an accident risk reduction of at most 10% (Ranta & Kallberg 1996).

Studies have shown weather-related information to also affect other safety-related factors such as headways, attention, alertness, passing decisions etc. These effects do not, however, eliminate the risk difference between adverse and good weather and road surface conditions.

The more substantial effects of traffic control systems indicate that drivers seem to require clear instructions to "correct" behaviour in the form of e.g. speed recommendations. The impact evaluations of traffic management and control systems indicate that the accident re-

ductions due to these systems are ca. 10 - 30%. The efficiency of these systems is closely linked to the operation of the control system, as an efficient system responds quickly and accurately to the conditions and does not give too high speed recommendations in any circumstances. Too high speed recommendations will result in increased accident risks.

The most efficient means probably involve "forcing" the behaviour to the safe limits with the help of in-vehicle control devices, but these will not be easily accepted by the drivers.

Hence, the answer to the question of the title is "Yes". Traffic management and information can improve road safety. Much research effort has , however, still to be undertaken with regard to affecting driving behaviour before the accident risks in adverse conditions will be of similar magnitude as those in good conditions. The Finnish National Road Administration is currently continuing such research within the scope of the Euroregional VIKING action supported by the TEN-T grants of the European Community.

Acknowledgements

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References

Almquist, S. and Nygård, M. Lund 1997. "Demonstrationsförsök med dynamisk hastighetsanpassning i tätort." Vägverket, Program för Väginformatik, Lägesrapport 1997-01-10.

Balz, W. and Zhu, J. Stuttgart 1994. "Nebelwarnsystem A8 Hohenstadt - Riedheim. Wirkungsanalyse". Landesamt für Strassenwesen, Baden-Württenberg & PTV Consult GmbH.

Cooper, B. R. and Sawyer, H. E. Crowthorne 1993. "Assessment of M25 automatic fog-warning system - Final report". TRL Project report 16. Crowthorne. 11 p.

Heinijoki, H. Helsinki 1994. "Kelin kokemisen, rengaskunnon ja rengastyypin vaikutus nopeuskäyttäytymiseen". Tielaitoksen selvityksiä 19. 99 p. ISBN 951-47-9098-7

Hirvenoja, E. Helsinki 1994. "Comprehension of variable message signs for road conditions". Finnra Reports 62/1994.

Hogema, J. H., van der Horst, R. and van Nifterick, W. 1996. "Evaluation of an automatic fog-warning system". Traffic Engineering + Control, November 1996. pp. 629 - 632.

Juhala, M. Helsinki 1994. "Esiselvitys automaattisesta liukkauden havaitsemisesta liikenteessä". Tielaitos, Liikenteen hallinta -projekti. Tielaitoksen selvityksiä 63/1994. 52 p.

Ranta, S. and Kallberg, V-P. Helsinki 1996. "Ajonopeuden liikenneturvallisuusvaikutuksia koskevien tilastollisten tutkimustenn analyysi [Analysis of statistical studies of the effects of speed on safety]." Finnish National Road Administration, Finnra studies 2/1996. 91 p. + app. 12 p. TIEL 320 0020.

Luoma, J., Rämä, P., Penttinen, M. and Harjula, V. "Driver responses to variable road condition signs." Proceedings of the Conference on International Cooperation on Theories and Concepts in Traffic Safety, Lund, Sweden, November 5-7, 1997, in press.

Penttinen, M., Luoma, J. and Rämä, P. "Information needs of Finnish drivers." Proceedings of the 4th World Congress on Intelligent Transport Systems, Berlin, October 5-10, 1997, in press.

Pilli-Sihvola, Y. Birmingham 1996. "Weather-related traffic management - E18 Finnish test area". In: SIRWEC 8th International Road Weather Conference, April 17 - 19, University of Birmingham - UK, Proceedings. SIRWEC & Vaisala. Pp. 161 - 170.

Röine, M. Helsinki 1993. "Kuljettajakäyttäytyminen kaarre- ja jonoajossa." Tielaitoksen selvityksiä 87. 34 p. ISBN 951-47-8771-4.

Rämä, P., Kulmala, R. and Heinonen, M. Helsinki 1996. "Muuttuvien kelivaroitusmerkkien vaikutus ajonopeuksiin, aikaväleihin ja kuljettajien käsityksiin". Helsinki, Tielaitos, keskushallinto. Tielaitoksen selvityksiä 1/1996. 77 p.

Rämä, P. "Effects of weather controlled traffic management system on driver behaviour." Proceedings of the 4th World Congress on Intelligent Transport Systems, Berlin, October 5-10, 1997, in press.

Saastamoinen, K. Helsinki 1993. "Kelin vaikutus ajokäyttäytymiseen ja liikennevirran ominaisuuksiin". Tielaitoksen selvityksiä 80. 48 p. ISBN 951-47-8139-2.

Öberg G. 1993. "Traffic on ice and snow". Nordic Road & Transport Research No. 3/1993. pp. 32 - 33.

CAI-SYSTEM UTILIZATION IN THE RE-EDUCATION OF OLDER DRIVERS' HAZARD PERCEPTION

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1. INTRODUCTION

Several drivers' aptitude tests have been developed in Japan which contribute to driving safety, e.g., The Speed Anticipation Test, developed by Maruyama and Kitamura (1961) and The Discrimination Reaction Test of Multiple Performance Type, by Nagatsuka and Kitamura. (1961). These aptitude tests have been quite successful with regard to the task of identification of safe and unsafe drivers, and in terms of contributing to the scientific understanding of drivers' psychological mechanisms as operative in traffic accidents. However, the tests are not particularly concrete, i.e., situation-specific, as teaching materials. A new trend has recently emerged. Traffic psychologists in Japan are now more interested in advice-oriented testing (e.g. Fukazawa,N. 1985, Nagayama, ,Y. and Renge,K.1989) ; we aim to make diagnostic tests, often using such materials as illustrations, movies and computer graphics which are more situation-specific, directly relating to actual road situations. After testing, the same materials can be used for follow-up teaching purposes; by using small group discussion methods, drivers can attempt to understand typical accident patterns on the road.

These advice-oriented tests focus particularly on external hazard perception on the road However, there is another hazard which is more difficult for drivers to detect. It is the internal danger which drivers themselves have. It is important for drivers to assess their driving abilities objectively, because compensatory behavior can only be expected when drivers understand their own weak points (Simms, B. 1993, Cooper, P.J. et.al. 1993). It is, however, not easy for drivers to make accurate self-evaluation of their driving skills. Drivers usually exhibit an optimistic bias, showing a tendency to over estimate the excellence of their own driving skills (Mackenna, F., Stanier, R. and Lewis,C. 1991, Ota, H. 1996, Keskinen,E. 1997). One important factor determining the road safety of drivers is the degree of adequacy in self-assessment of ability. In particular, an over self-confidence can contribute to unsafe behavior (Keskinen, E. et.al. 1994). Drivers' education should take into account not only external hazard perception but also the internal sort. However we currently lack an educational system which would help drivers achieve accurate self-evaluation.

2. PURPOSE

Accurate self-evaluation is especially important for older drivers. Older drivers must be able to discern which kind of psychological functions relating to driving have deteriorated or are likely to. These drivers can compensate for their weak point by adapting their behavior; if he/she is aware that night-time vision has deteriorated, he/she can try not to drive at night so often. It is also important for older drivers to know when they should give up driving. Older people need

information about their own psychological functions as drivers to determine the appropriate limits of their driving careers. However, there are not yet good diagnostic tests and training systems available, allowing drivers to gain skill in self-evaluation. Considering this present condition, Ota is developing a system which employs the computer in a program for diagnostic testing and education of external hazard perception.

The aim of the study is to assess the effect of the experimental education program which was conducted upon the occasion of older drivers' renewal of their drivers' licenses; the aim of the program is, (1) to offer older drivers an opportunity to re-evaluate their driving skills, especially their hazard-perceptual ability on the road, and (2) to develop a re-education curriculum for older drivers focusing on external hazard perception and the development of the skill of accurate self-evaluation by analyzing the effects of the experimental education conducted by the author.

3. METHOD

Ota (1996) is developing his own advice-oriented tests on hazard perception with Hitachi Co,Ltd., Hitachi Microsoft Co,Ltd. and Kigyokaihatu Center Co,Ltd) using a personal computer with a touch-panel monitor. The system is constructed with a Hitachi personal computer (Hitachi Flora-DM1), MPEG board RM-LT2 (Software Japan Co.LTD), 17" display with touch panel-TD17(Tachimbana Shoukai Co. LTD). After observing a traffic scene from the driver's seat for a few seconds, subjects are shown a still picture of the scene and are asked to point out the dangerous objects and places on the road. The test consists of seven scenes in each of three themes, i.e., intersections, residential streets, and various traffic scenes which drivers might encounter on the way to their offices. After finishing the test, subjects receive an evaluation for three phases of their hazard-perceptual ability:

phase 1: the ability to detect hazardous objects visible from the car

phase 2: anticipation of other traffic participants' behavior

phase 3: the ability to detect dangers hidden on the road

The author devised an experimental re-education program for older drivers in conjunction with the renewal of their driver's license. Prior to involvement in the program, participants were asked to complete a questionnaire in which they were asked to evaluate their own ability in regard to several aspects of hazard perception. The education program itself was carried out with the use of a CAI (Computer Aided Instruction) system, " Yochiro", mentioned above. In this experimental education program, intersection scenes were used in testing and education because older drivers characteristically have problems at intersections. Due to the group education setting, instead of

touching a panel monitor to show the hazardous objects/places, subjects were asked to mark those on illustrations which they had been previously given by the trainer. Seven scenes were shown to the subjects on a wide screen at the front of the room using a projector connected to the computer. Self-diagnostic testing using the CAI system was followed up by discussion among the participants about hazards on the road. The participants were asked to talk about the hazards which they had marked and describe the reasons, referring to the scenes they had been shown. The trainer was required to give attention to all those actively participating in the discussion. The subjects were then given a questionnaire in which they were asked to reevaluate their ability and identify their problem areas in hazard perception.

4. RESULTS

4.1 Participants

73 drivers over 65 years old participated in the experimental education class. The number of participants in a class is between 2 and 10 drivers. Tests were carried out with time limits, i.e., they were given 30 seconds per every 7 scenes for checking and marking hazards on the road in the illustration. Wondering if this might not be enough time after finishing two classes, the trainer tried removing the time limit for the other 53 participants. Analysis was mainly carried out for the 53 participants, except for analysis of the effects of a time limit on the detection of hazards on the road.

4.2. " How often do you drive in a week?"

Three groups were classified by age: (1) 65 - 69 , (2) 70-74, (3) over 75 . The number of participants in each group was respectively 26, 16 and 11 including two female (69 and 70 years old).

More than 60 percent of older drivers who are 65-69 years old drive every day. Even drivers who are over 75 years old tend to drive their cars more than two or three days in a week. It can generally be said that older drivers drive very often and lead active lives.

Fig. 1 "How often do you drive in a week?"

4.3 " Are you afraid that your physical strength is declining?"

2 participants(3.9%) answered "often", 16 participants (30.2%) answered "sometimes, 19 participants (35.8%) answered "seldom" and 14 participants (26.4%) answered "not at all". 65 percent of the participants were not particularly concerned about the deterioration of their physical strength.

Fig.2 "Are you afraid that your physical strength is declining?"

4.4 " Do you have any problems while driving lately?"

Participants who are over 75 years old reported some vision problems while driving at night and on rainy days. 40 percent of them, however, did not report any problems.

Fig. 3 " Do you have any problems while driving lately?"

4.5 "What are your strong and weak areas in hazard perception?" -Comparison of self-assessment before and after testing and teaching-

With regard to most areas of hazard-perceptual ability, participants evaluated themselves higher than average before testing and teaching. However, participants less than 75 years old revised their self-assessment downward on all items toward after testing and teaching. Participants over 75 years old, on the other hand, did not change their self-assessment.

Fig. 4 "What are your strong and weak areas in hazard perception?"
(before testing and teaching)

Fig. 5 "What are your strong and weak areas in hazard perception?"
(after testing and teaching)

4.6 Comparison of test scores by age

Table. 1 shows the average test scores and standard deviation in each of three different ages. The

differences between scores are not significant (F=0.985, p=0.381).

Table 1 Comparison of test scores by age

The author has obtained the test scores of younger drivers (20 - 65 years old, average age; 38.2 years old, SD; 11.4) in the process of developing this CAI system "Yochiro". The average of these younger drivers' scores was 19.4 and the standard deviation was 7.2. It can be said that drivers under 65 have higher scores on hazard perception.

4.7 Comparison of the results of the test between groups who took the test with time limitation and without time limitation, by age.

Tests were carried out with a 30-second time limit for 20 participants and without a time limit for 53 participants. Under the time limit condition drivers over 70 showed lower scores compared with younger drivers aged 65-69 (drivers were regrouped into two groups because it was difficult to analyze the data as the numbers of participants tested with the time limitation were not enough). However, without a time limit, the older older drivers (over 70) achieved the same scores as did the younger older drivers did.

Fig. 6 Comparison of the results with the time limit
and without the time limit

4.8 The relationship between self-assessment and the test scores for hazard perception

The correlation coefficient between the test scores and the average score of five items of self-assessment which was found in the evaluations of 53 participants before testing and education was -0.035. The after-testing correlation coefficient between self-assessment and test scores was -0.139. No relationship between subjective evaluation and objective test scores on hazard perceptual ability could be found.

4.9 " In today's class, what tasks did you learn would improve your driving safety?"

As described above, the participants' self-assessment was higher than average before the class and lower afterwards. At the same time they identified their individual difficulties in regard to

hazard perception on the road. Almost 80 percent of the participants realized a need to be more careful about hidden hazards on the road and 50 percent of them gained insight into other weak areas.

Fig.7 " In today's class, what tasks did you learn would improve your driving safety?"

5. DISCUSSION

The analysis examined the effect of the education program on participants' assessment of their own driving safety, especially in hazard perception.

One of the most interesting results of this study was the lack of a relationship between self-assessment and objective hazard perceptual ability as shown in the result in section 4.8, which offers evidence that drivers do not possess accurate understanding of their own objective abilities as drivers. Previous studies have shown that most drivers usually tend to assess themselves as safer drivers than do others (Mckenna, F., Stanier, R. and Lewis, C. 1991). The drivers who participated in this class exhibited the same tendency despite the fact that their objective hazard perceptual ability had deteriorated compared with younger drivers. In the questionnaire filled out prior to diagnostic testing and teaching, they assessed themselves as better than other drivers with regard to hazard-perceptual ability. However, most participants' self-assessments shifted to lower levels after the subsequent testing and teaching, which can be seen to be the effect of the experimental education. Those drivers older than 75 years old, however, displayed a different tendency. Their self-assessment did not change; their self-assessment after the class was almost the same as before the class, and they still assessed themselves as better than average. Several factors can be considered to possibly contribute to this tendency. Participants under 75 might expect higher test scores before the testing than those they actually achieved. They realized that their objective ability of hazard perception was lower than what they had previously expected, and as a result, their self-assessment shifted to lower levels. On the other hand, participants over 75 might not expect such high scores before the testing. As a result, their self-assessment was unchanged. The problem is that the level of the self-assessment of over 75 is higher than the average level even though they achieved lower scores than the average. This fact suggests that drivers over 75 have difficulties in adjusting their self- assessment even when they have been given objective test results indicating that their safe driving skills have deteriorated. Studies show that older drivers have virtually unbroken self-confidence with respect to their driving ability (OECD 1984). It could be because of the rigidity common among the elderly, which can hinder them in learning from their own mistakes

(OECD 1984).

However, studying the results of the questions asked about their safe driving tasks in the questionnaire, participants over 75 gained awareness of ways of safer driving; 6 of 11 participants mentioned that they understood their own problems in hazard perception and 7 participants identified their problems in the perception of hidden hazard on the road. The method of self-evaluation itself using a 5 scale evaluation method should also be discussed in regard to whether this way of rating is suitable for older drivers.

The time limitation in the diagnostic testing procedure affected older drivers in particular. When there was no time limitation, there were no differences in the scores between younger older drivers (65-69) and older older drivers (over 70). It means that even drivers over 70 years old do not lose hazard-perceptual ability when adequate time is available. However, when they feel pressured to complete tasks in a given time, their hazard-perceptual ability can deteriorate significantly. Studies show that the elderly experience a deterioration of their ability to process information within a short time period (Parasuraman, R. and Nestor, P. 1993). The results of the present study reinforce this, with time limits being a problem for older drivers. However, it is interesting that the results of the study also show that even drivers over 70 years old do not show any deterioration in hazard perception, when the time limitation was removed. It means that when older drivers have enough time to process information or, in another words, if older drivers do not have a time limitation, they can be expected to adequately manage their safety on the road. The time factor is very important for traffic safety. Further studies should be conducted to clarify the effect of the time limitation on hazard perception. Also, further experimental education should be planned to explore the possibility of older drivers improving their driving behavior on the road via re-education in hazard perception by using such teaching materials as CAI systems. It is especially important to understand how the participants' changes in self-assessment can make their driving behavior safer.

REFERENCE

Cooper, P.J., Tallman, K., Tuokka, H. and Beattlie, B.L. : Safety - related driving performance changes in older : Journal of Traffic Medicine, Vol. 21, No. 1, 21-27, 1993

Keskinen, E. , Hatakka, M., Katila, A., Laapotti. S., Ota. H. and Fukazawa. N. New drivers' assessment of risks and driving skills in Japan: Effects of sex, age and learning environment. IATSS Research. vol.18, No.1, 16-22, 1994

Keskinen, E. : Self-evaluation and feedback as tools in Finnish drivers training and traffic safety work. 55th Congress of Japanese Traffic Psychological Association. 1997

Fukazawa, N. : On the risk perception test (tentative name) 1, Japanese Journal of Applied Psychology, Vol. 8, 1-12, 1983

McKenna, F., Stanier. R. and Lewis. C.: Factors underlying illusory self-assessment of driving skill in males and females. Accid. Anal. Prev. Vol.23. No.1, 45-52, 1991

Maruyama , K., and Kitamura, S.: Speed anticipation test: A test for discrimination of accident proneness in motor driver, Tohoku Psychologica Folia, Vol 20, 13-20, 1961

Nagatsuka, Y. and Kitamura, S.: Discriminative Reaction Test of Multiple Performance Type: a test for discrimination of accident proneness in motor driver, Tohoku Psychologica Folia, Vol 20, 21-34, 1961

Nagayama, Y and Renge, K.: The manual of diagnostic testing for risk perceptual ability (in Japanese), Kigyo Kaihatsu Center Co.LTD. 1989

Simms, B. : The characteristics and driving patterns of drivers over seventy. TRL Report 26, 1993

OECD : Traffic Safety of elderly Road Uses. Report prepared by and OECD Scientific expert Group in Co-operation with WHO. 1984

Ota, H. : Studys on causation of older drivers traffic accidents. Report of IATSS's project research. 1996

Ota, H. : Kiken Yochi Kunren TEST "Yochiro". Kigyo Kaiyatsu Center. 1996

Prasuraman, R. and Nestor, P. : Attention and driving. -Assessment in elderly individuals with Dementia-, Medical Considerations in the Older driver. Vol.9, No.2, 1993

Table 1 Comparison of test scores by age

Total score	average	SD
65-69 years old	14.8	4.6
70-74	12.7	4.3
75-	13.9	5.1

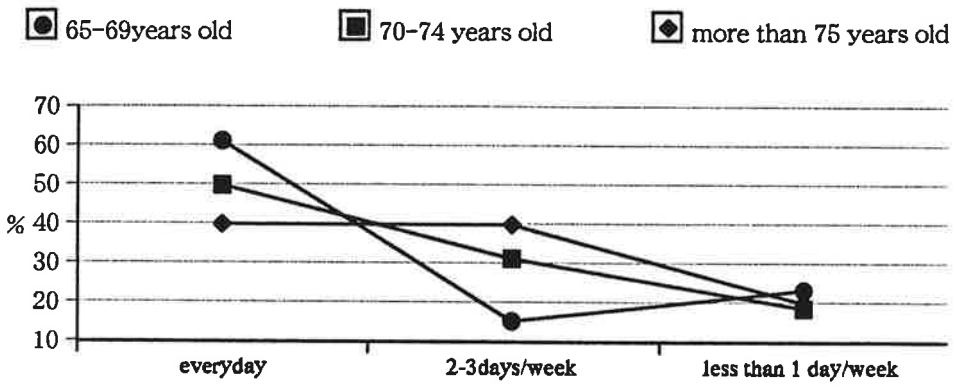


Fig.1 "How often do you drive in a week?"

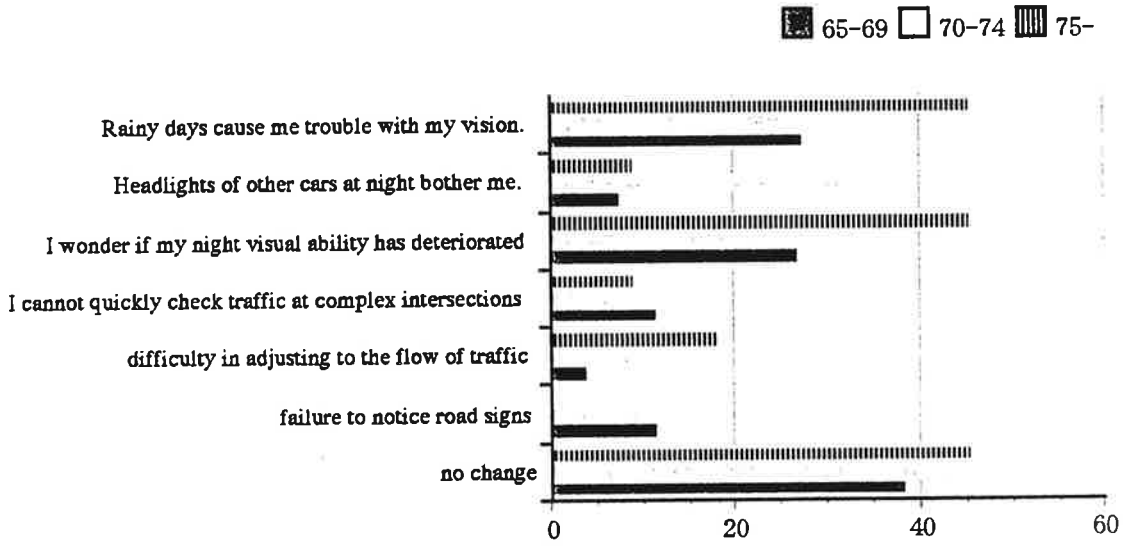


Fig2 "Are you afraid that your physical strength is declining?"

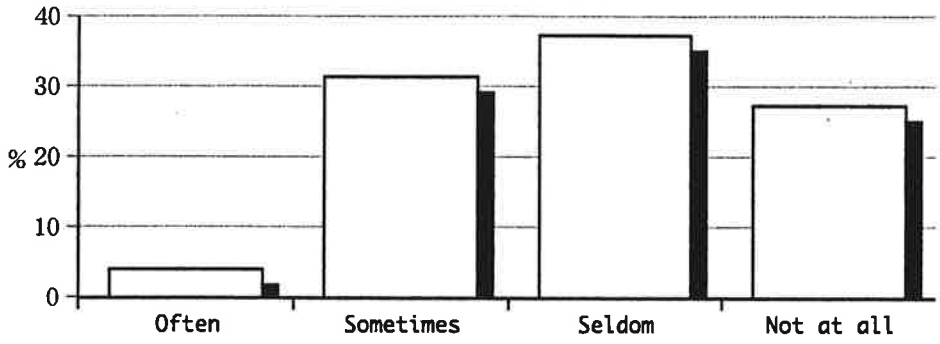


Fig. 3 " Do you have any problems while driving lately?"

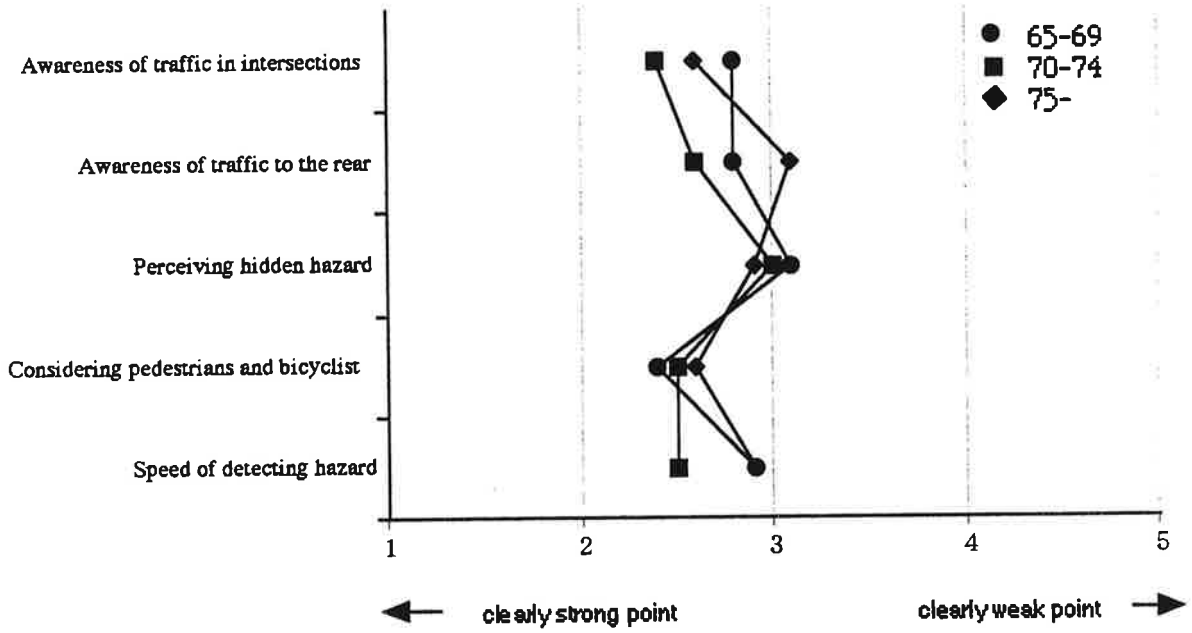


Fig. 4 "What are your strong and weak components in hazard perception?"

(before testing and teaching)

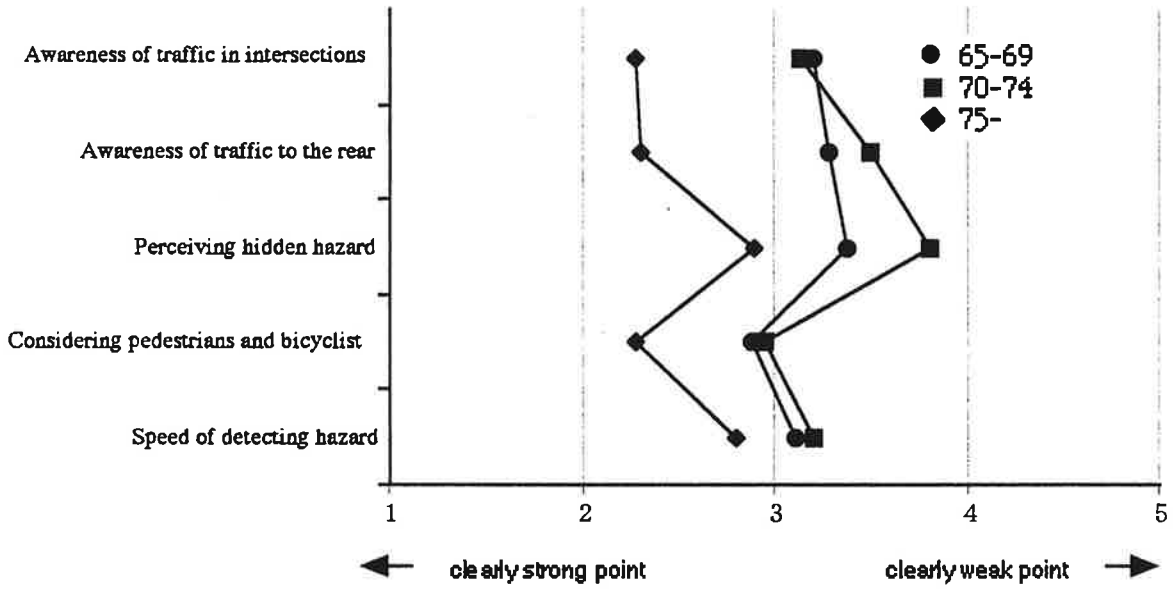
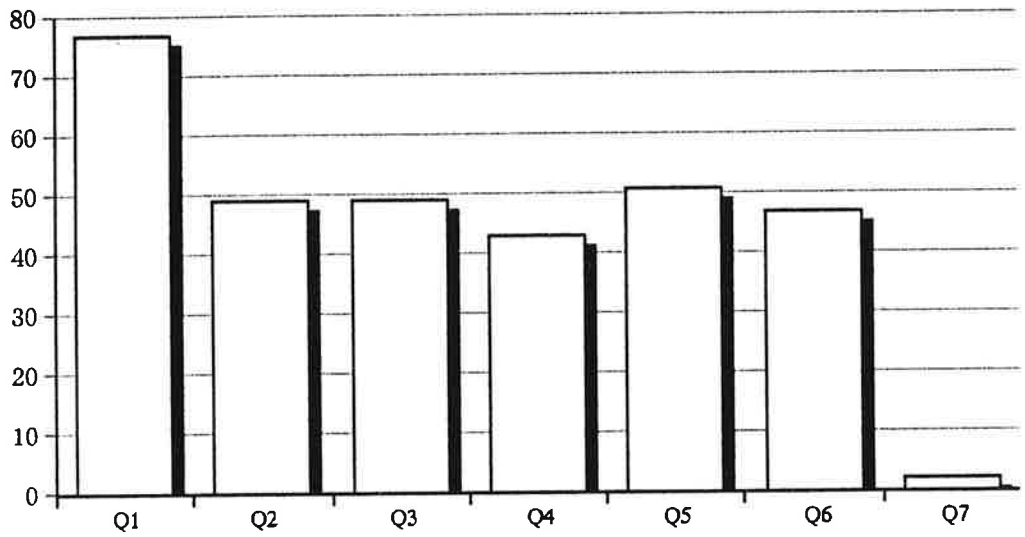


Fig. 5 "What are your strong and weak components in hazard perception?"

(after testing and teaching)



Q1. " I have to be more careful about hidden hazards on the road."
Q2. " I have to check my rearview mirror more often."
Q3. " I learned typical accident patterns on the road"
Q4. " I learned the importance of an active attitude in detecting hazards."
Q5. " I could clearly understand my weak points in hazard perception."
Q6. " I realize that my hazard perception on skills have deteriorated, and I will drive more carefully."
Q7. " I did not get any new information from this class"

Fig6 " In today's class, what tasks did you learn would improve your driving safety?"

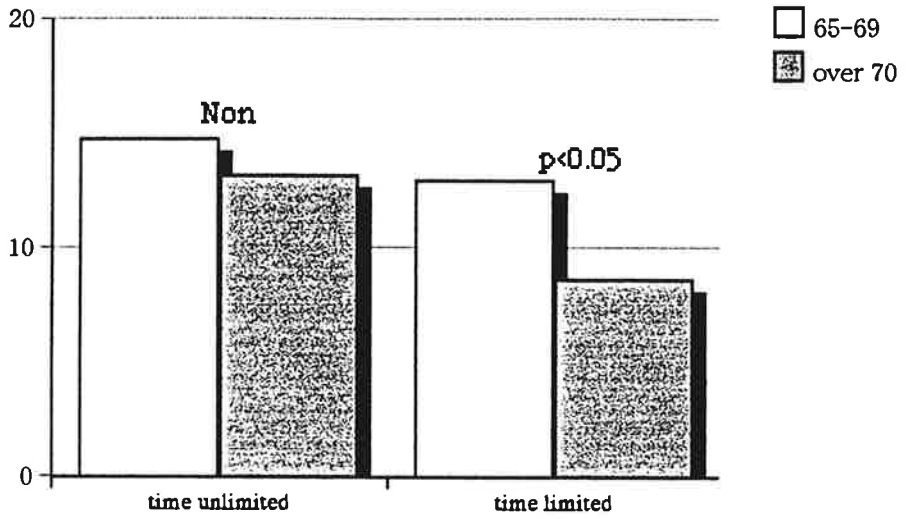


Fig. 7 Comparison of the results with the time limit and without the time limit

Lane-keeping behaviour at profiled road markings on motorways: A before-and-after study

Richard van der Horst[1]
Alexander de Vos[1]
&
Engbert Folles[2]

1 Introduction

Accident statistics of national rural roads indicate that a substantial part consists of single-vehicle accidents (26%; Slangen, 1992). On motorways, 36% of all injury accidents consists of emergency-lane accidents; heavy vehicles were involved in 47% of those accidents (Mathijssen, 1987). Tromp (1993) found that in 32% of all accidents on road sections of motorways at least one vehicle ran off the road. Many of these accidents may result from problems with lane keeping. To reduce the unintended crossing of the edge line, the application of profiled road markings may help to reduce the number of those accidents. Profiled road markings have a better visibility in adverse wheather conditions, and the acoustic/haptic functioning may result in an additional warning while crossing. In The Netherlands with many motorways in a densely populated area, traffic noise is an important issue. Adequate noise production of profiled road markings within vehicles is allright, as long as it does not result in an increase of the noise nuisance to the environment. Therefore, existing high-frequency profiled road markings could not be applied and a new type of profiled road markings had to be developed. Based on earlier experience in France and Germany, a special "saw tooth" profiled marking was developed and tested on the road at two exerimental motorway locations with respect to noise and vibration production, and with respect to speed and lane-keeping behaviour (Folles, 1993). The limited scope of the study did not permit a long-term safety evaluation on the basis of accident statistics. In Chapter 2 a brief description of the type of profiled road marking is given. Chapter 3 presents a video-based behavioural observation study to evaluate driving behaviour in terms of speed and lane-keeping. Finally, conclusions, and recommendations for the application of profiled road markings are given in Chapter 4.

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2 The "saw-tooth" profiled road marking

As indicated in Chapter 1, the profiled road marking to be developed must induce a noticable sound and vibration within the vehicle for the driver on the one hand, but on the other it must result in as little noise as possible in the surrounding area. This starting point almost automatically results in a profile that induces vibrations in the low frequency range. In Germany, some experience was gained with profiled road marking with the dimensions based upon the eigen-frequency of the wheel suspension of vehicles (9-11 Hz at speeds of 80 - 100 km/h results in an optimal discomfort). Noise measurements indicated that profiled road markings with a "saw-tooth" (of 0.50 m in length and a height of 7 mm above the regular marking, or 10 mm above the road surface) every 2.5 m did not significantly increase the noise level outside the vehicle (de Regt & de Roo, 1993). Based on these results, a slightly modified profiled road marking has been designed for Dutch circumstances, see Fig. 1.

Two motorway sections with a number of road-off accidents slightly above average were selected for the test, one location consisted of a straight road section (A50, section Heerde-Hattem, km 230.5 - 233.5), the other had a slight left curvature (A28, Elspeet-Epe, km 63.7 - 65.7). On both sections of a two-lane dual carriageway motorway the left and right edge line were removed and replaced by the new profiled road markings. Both locations had a viaduct (no motorway entries or exits) from which unobtrusively video recordings could be made (see Chapter 3). Noise measurements (Eisses & Biegstraaten, 1994; 1995) revealed that individual passages of passenger cars that drive on the profiled road marking result in a significant increase of the noise emission of about 3.5 dB(A) (measured at a 7.5 m distance from the edge line). For trucks no significant increase could be distinguished. Given that passenger cars and trucks only touch the road marking for 0.12 and 1.3% of the time, respectively (CROW, 1987) hardly any increase in noise emission to the environment is to be expected according to the regulations from the Dutch Noise Abatement Act. In a passenger car the "saw-tooth" profiled road marking is clearly tangible to the driver. Truck drivers experience the induced vibrations to a lesser extent.

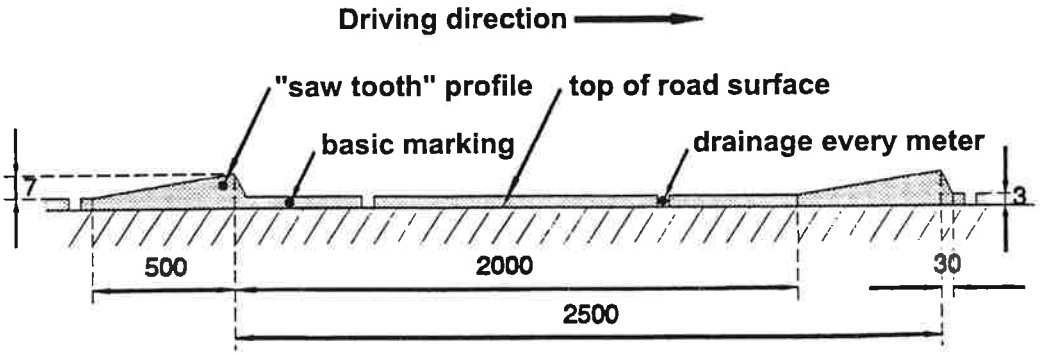


Fig. 1 Saw-tooth profiled road marking as applied on two experimental locations in The Netherlands.

3 Behavioural study

3.1 Introduction

In good visibility conditions (daytime, dry road surface) the visibility distances of conventional road markings (painted, thermoplast) are in the same range as those of profiled road markings. This is also the case at night on unlighted roads (Blaauw & Padmos, 1981). On a wet road surface, however, the visibility of conventional markings is reduced considerably, whereas the visibility of several profiled road markings still is as good or even better than on dry roads (Blaauw et al., 1983). The first hypothesis of the possible effect of profiled road markings on lane-keeping behaviour is stated as follows:

On a wet road surface the better visibility of profiled road markings results in less edge line exceedances than in similar conditions with conventional markings.

In such circumstances, a better visibility could possibly result in higher driving speed.

The crossing of a profiled marking may give the driver an additional warning (acoustic/haptic) that increases driver's attention level. Therefore, a second hypothesis is formulated:

By a better warning when crossing profiled road markings the durations and/or sizes of lane exceedances are smaller than with conventional markings.

Because the majority of lane exceedances on motorways is caused by heavy vehicles (90% in a French study; Christian, 1991) a distinction has to be made between passenger cars and heavy vehicles.

3.2 Method

At the two experimental motorway sections, as indicated in Chapter 2, a before-and-after behavioural observation study has been conducted. An experimental design with location (A28, A50), type of road marking (before: conventional, after: profiled), the status of the road surface (dry, wet) and the lighting condition (daytime, night) as the independent variables, would result in 2*2*2*2 = 16 measurements. At the A50 location, however, the limited time schedule did not allow for sufficient observations at a wet road surface in the before period. On the A28, only a limited number of observations could be made during night time with a wet road surface. On both locations unobtrusive video recordings were made with video cameras mounted above the road on a viaduct (without motorway entries or exits). At each location, two cameras covered a road section of about 700 m, see Fig. 2. Only the right traffic lane has been analyzed.

From the video recordings a quantitative analysis has been conducted with speed

measurements of 100 free-driving passenger cars and 100 free-driving trucks in each condition. Duration and size of line crossings were measured by superimposing six electronic lines on the video image in longitudinal direction on the emergency lane, with a 0.50 m lateral separation each. According to Violette (1993), also driving on the edge line itself was included in the analysis.

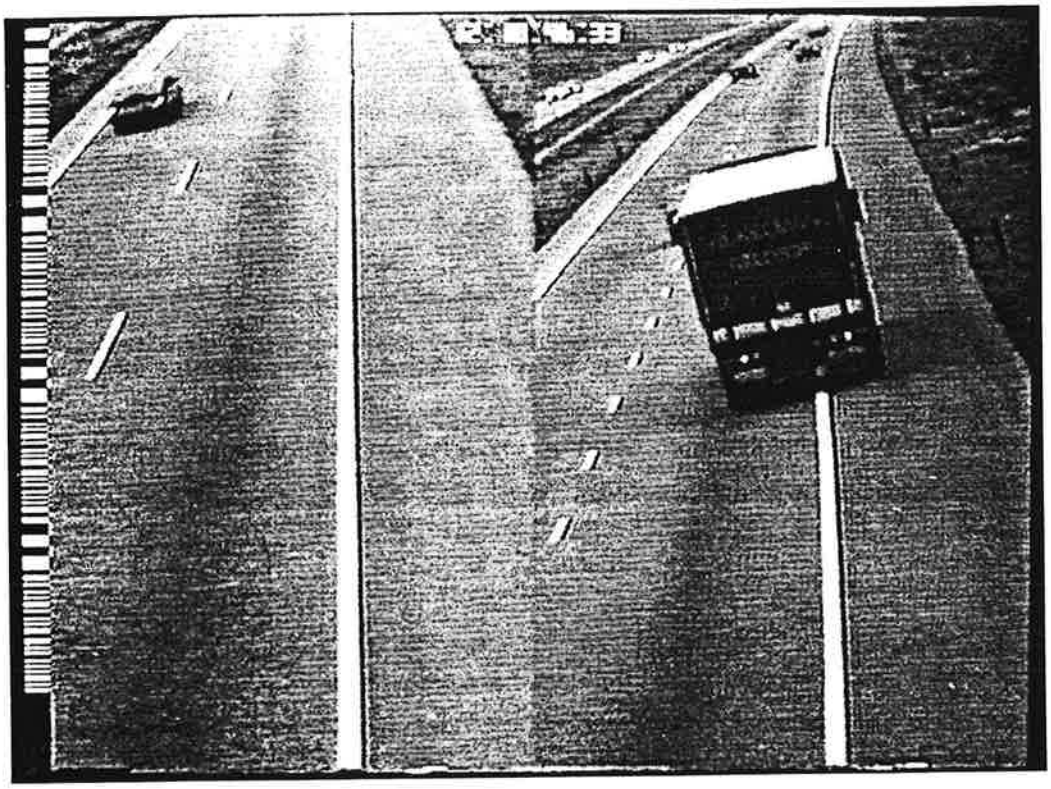


Fig. 2 Example of the video recordings on the A50 location.

3.3 Results

The results of the behavioural observation studies are given in detail by Van der Horst and Bakker (1993, 1995) and De Vos, van der Horst and Bakker (1995, 1996). In the context of this paper, only a summary of the results is presented.

Speed
The average speed of free-driving vehicles at both locations is given in Table I (before measurements at the A50 location with wet road surface are not available). At the A50 no general effect of the type of road marking was found on speed. On a dry road surface, passenger car speeds were somewhat higher with profiled road markings (before) than with conventional markings (after). Trucks drove somewhat slower in the after period, probably mainly due to the introduction of speed governors for trucks in the period between the two periods. As an average over all conditions, profiled road markings on the A28 resulted in a

1.8 km/h higher speed. Further analysis indicated that this speed increase could be contributed to an increase in speed for passenger cars at a wet road surface. During daytime on a wet road, drivers of passenger cars drove about 4.1 km/h faster with profiled road markings than with conventional markings, and 4.7 km/h faster during night time. On a dry road no significant increase in driving speed was observed. The speed of trucks did not change significantly, neither on a dry or a wet road surface.

Table I: Average speed (km/h) of free-driving passenger cars (PC) and trucks (TR) per condition (each n=100).

		Dry				Wet		
		A50		A28		A50	A28	
		Before	After	Before	After	After	Before	After
TR	Day	87.8	86.4	86.9	87.6	83.4	86.3	87.2
	Night	81.3	79.6	81.8	82.3	79.7	82.2	81.8
PC	Day	116.6	118.6	115.7	116.7	106.0	109.6	113.7
	Night	111.6	113.6	112.0	114.4	98.7	101.0	105.7

Number of edge-line exceedances

Table II gives the number of right edge-line exceedances as a percentage of the total number of vehicles passed, subdivided by type of vehicle, light condition, location, and type of road marking (before: conventional; after: profiled).

Table II: Number of edge-line exceedances as a percentage of the total # of vehicles passed (PC: passenger car; TR: truck) per condition.

		Dry				Wet		
		A50		A28		A50	A28	
		Before	After	Before	After	After	Before	After
TR	Day	14.1	17.4	7.2	9.1	11.0	6.0	5.9
	Night	7.9	6.9	9.6	7.9	6.0	7.3	4.1*
PC	Day	1.3	1.9	0.4	0.1	1.8	0.1	0.3
	Night	0.2	0.3	0.2	0.2	0.3	0.4	0.1*

* Based on a limited observation time only.

On the A28 no general effect of the type of road marking on the number of line exceedances was found. A further analysis reveals that at night with profiled road markings the number of exceedances is reduced, especially on a wet road surface. At both locations trucks drive on or over the edge line much more frequently than passenger cars.

Exceedance size

Profiled road marking on the A28 only influences the size of the edge-line exceedance in the dry daytime condition and the wet night condition. Relatively, less frequently one drives *on* the profiled edge line and more frequently *over* the line than with conventional markings. No difference occurred between passenger cars and trucks. For the A50 a similar result was found (only dry condition available).

Duration of edge-line exceedances

The average duration of edge-line exceedances is given in Table III. On the A50 both passenger cars and trucks drive shorter *on* the profiled edge line than on the conventional edge line. In none of the other conditions a significant difference in exceedance durations was found.

Table III: Average duration of edge-line exceedances (s) by type of vehicle (PC = passenger car; TR = truck) per condition.

		Dry				Wet		
		A50		A28		A50	A28	
		Before	After	Before	After	After	Before	After
TR	Day	7.88	7.34	5.15	4.23	7.58	5.67	6.49
	Night	7.51	8.37	4.40	5.63	7.90	5.56	4.16*
PC	Day	5.79	3.65	3.34	3.39	4.38	5.94	4.98
	Night	4.50	4.16	3.95	2.34	3.82	7.90	2.64*

* Based on a limited observation time only.

4 Conclusions and recommendations

Profiled road markings of the "saw-tooth" type as applied on two experimental locations (with a "saw-tooth" length of 0.50 m, height 7 mm, repeated every 2.50 m) results in a minimal increase in noise emission to the environment, whereas the sound within a passenger car is well perceivable (less so in the cabin of a truck). The vibration induced by the "saw-tooth" is tangible in both passenger cars and trucks.

From the behavioural observation study it is concluded that an improved visibility of profiled road markings in adverse conditions (wet road, night) contributes to a reduced number of edge-line exceedances. The duration of driving *on* the edge marking is reduced with profiled markings for both passenger cars and trucks. However, on a wet road surface profiled road markings result in higher driving speeds of passenger cars. With profiled road markings drivers avoid driving *on* the marking with sometimes the consequence of driving relatively more frequently with the right wheels *over* the edge line.

Based on these results, it is recommended to practise reservedness with applying profiled road markings on motorways on a general scale. The profiled road marking of the "saw-tooth" type results in less edge-line exceedances in adverse visibility conditions, but at a cost of higher speeds. By that, the net safety effect may be less than originally expected. Only at locations where road-off accidents occur relatively frequently, the application of profiled road markings is to be considered.

Acknowledgment

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References

Blaauw, G.J. & Padmos, P. (1981). *De zichtbaarheid s' nachts van wegmarkeringen op droge en natte wegdekken.* (The nighttime visibility of road markings on dry and wet road surfaces). (Report IZF 1981 C-20), Soesterberg: TNO Human Factors Research Institute.

Blaauw, G.J., Padmos, P., Alferdinck, J.W.A.M. & Hoogeweg, F. (1983). *De zichtbaarheid s' nachts van negen verticaal geprofileerde wegmarkeringen op droge en natte wegdekken.* (The nighttime visibility of nine vertically profiled road markings on dry and wet road surfaces). (Report IZF 1983 C-24), Soesterberg: TNO Human Factors Research Institute.

Christian, B. (1991). *Mesures d'efficacité des Bandes de Rives Sonores sur Autoroute. Metz, F*, Metz: Cete de l'est.

CROW (1987). *Zicht op wegmarkeringen*. CROW publicatie nr. 2, Ede: Stichting Centrum voor Regelgeving en Onderzoek in de Grond-, Water- en Wegenbouw en de Verkeerstechniek.

Eisses, A.R. & Biegstraaten, F.J.W. (1994). *Experimenteel onderzoek naar de geluid- en trillingssignalering van de wegmarkering in het proefvak langs de A50.* (Report TPD-HAG-RPT-94-0171), Delft: Technisch Physische Dienst TNO TU Delft.

Eisses, A.R. & Biegstraaten, F.J.W. (1995). *Experimenteel onderzoek naar de geluid- en trillingssignalering van de wegmarkering in het proefvak langs de A28.* (Report TPD-HAG-RPT-950059), Delft: Technisch Physische Dienst TNO TU Delft.

Folles, E. (1993). *Projectplan AVV Geprofileerde Wegmarkering (GPW).* Projectcode ID 93.292, Rotterdam: Adviesdienst Verkeer en Vervoer Rijkswaterstaat.

Horst, A.R.A. van der & Bakker, P.J. (1993). *Koershoudgedrag bij geprofileerde wegmarkeringen; video-observaties in de nulsituatie op de A50.* (Lane-keeping behaviour at profiled road markings: Video observations in the before-situation on the motorway A50). (Report IZF 1993 C-35), Soesterberg: TNO Human Factors Research Institute.

Horst, A.R.A. van der & Bakker, P.J. (1995). *Koershoudgedrag bij geprofileerde wegmarkeringen; video-observaties in de nulsituatie op de A28.* (Lane-keeping behaviour at profiled road markings: Video observations in the before-situation on the motorway A28). (Report TNO-TM 1995 C-37), Soesterberg: TNO Human Factors Research Institute.

Mathijssen, M.P.M. (1987). *Vluchtstrookongevallen op autosnelwegen.* (Report R-87-16), Leidschendam: Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV.

Regt, M.J.A.M. de & Roo, F. de (1993). *Geluid- en trillingssignalering door wegdeklengtemarkering.* (Report TPD-HAG-RPT-93-0138), Delft: Technisch Physische Dienst TNO TU Delft.

Slangen, H.M.G. (1992). *Projectplan Geprofileerde Wegmarkeringen.* Rijkswaterstaat, Dienst Verkeerskunde, Rotterdam.

Tromp, J.P.M. (1993). *Ongevallen rijbaan-af op rijkswegen.* (Report SWOV R-93-55), Leidschendam: Stichting Wetenschappelijk Onderzoek Verkeersveiligheid.

Violette, E. (1993). Les marquages à protubérances et le débord des PL sur BAU d'autoroute. *Revue générale des routes et des aérodromes,* nr. 704, 36-39.

Vos, A.P. de, Horst, A.R.A. van der & Bakker, P.J. (1995). *Koershoudgedrag bij geprofileerde wegmarkeringen; video-observaties in de nasituatie op de A50.* (Lane-keeping behaviour at profiled road markings: Video observations in the after-situation on the motorway A50). (Report TNO-TM 1995 C-48), Soesterberg: TNO Human Factors Research Institute.

Vos, A.P. de, Horst, A.R.A. van der & Bakker, P.J. (1996). *Koershoudgedrag bij geprofileerde wegmarkeringen; video-observaties in de nasituatie op de A28.* (Lane-keeping behaviour at profiled road markings: Video observations in the after-situation on the motorway A28). (Report TNO-TM 1996 C057), Soesterberg: TNO Human Factors Research Institute.

Area wide illustration of car speeds

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1 Introduction

A system for the description of car speeds in an area wide concept has been developed. The aim is to meet the new strong ambitions to gain traffic safety benefits by reducing car speeds where vulnerable road users can be expected. Regarding traffic counts and traffic flow models we have a long tradition of illustrating the results on maps. These maps play an important role as a tool for traffic planning. If speed is going to play an equal important role in traffic planning and then especially the allocation of speed reducing countermeasures we need to illustrate the speed measurements in a similar way.

Area wide speed measurements will be illustrated in an emme/2 environment. The speed measurements are carried out by a hand held radar gun. A sampling procedure has been developed in order to optimise the trade of between accuracy and covering. A bootstrap procedure has been developed in order to obtain confidence intervals for the median and other percentile values. It is of great importance to keep track of the accuracy in the speed measurements since we have to minimise the number of cars to measure if we want to illustrate the speed behaviour on all kinds of streets, even those with low volume. A simulation procedure will be used to test the effect of reducing the number of measured cars to an absolute minimum.

During the period April to July -97(mainly May) a pilot-study has been carried out in the south-east part of central Lund. The study has involved a total of 43 measuring-sites evenly spread over the area. A total of 3068 car-speeds have been measured. The results from this study are presented in part 6 Results.

2 Aims

The aim of the project is to describe car-speeds in an area-wide sense. With that accomplished, it is possible to see where there will be potential problems with introducing the speed limit 30 km/h. Measuring is to be carried out in a way as to acquire enough data to describe the car-speeds using as little time as possible at each measuring-site. Illustration aims at simplifying the decision-making process. For example: 'Where do we have to make physical alterations to the street-design in order to achieve compliance with the new speed limit?'

3 Measuring-methods

The measuring has primarily been done on "free cars" whose speed aren't influenced by other cars. A Finnish video study(Pasanen 1993) shows that almost all car - vulnerable road user accidents involve free cars. Cars in a queue are very rarely involved in this kind of accidents. Vehicles in queue after a measured free car has been noted as driving at the same speed as the free. They are however not included in most of the samples used in this study.
In order to cover large areas, the amount of cars measured at each site should be minimised. Initially 100 cars were measured where possible. If 100 cars couldn't be measured within an hour, the measuring stopped anyhow. Acquired data was entered into an excel-model and then run through a Bootstrap-procedure in order to obtain confidence-intervals for the measures.

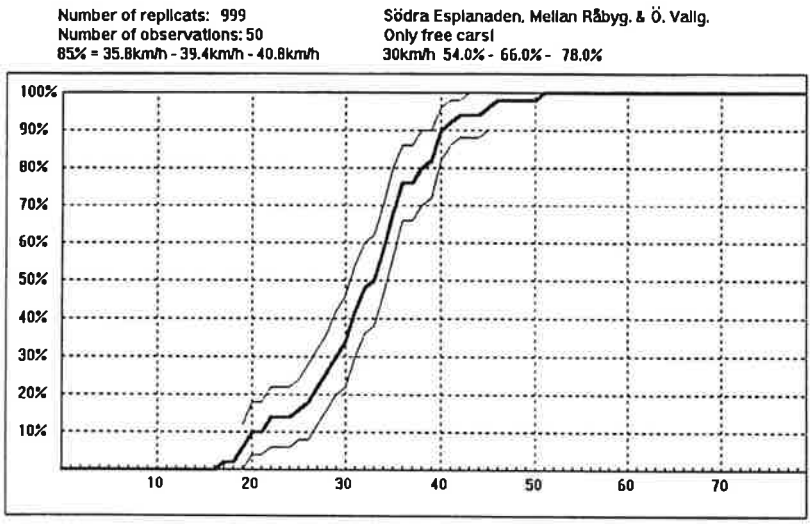
The demand for short-time measuring at each site calls for the use of hand held radar gun to measure speeds. It permits short time intervals from the end of measuring at one site to the start at the next one. In an urban area, about 15 minutes are required from end of measuring at one site to the beginning at the next one.

The measuring with the hand-held radar gun has been carried out according to the following principles:

- At every site, measuring was done until 100 free cars had been measured or 60 minutes had passed
- The measuring angle towards the cars was estimated so compensation for this error could be done
- Other parameters as travelling direction, type of vehicle, presence of vulnerable road users and influence from traffic-signals were also recorded
- At intersections, cars were measured 10 meters from the intersection.

4 Sampling

The data acquired in the process of measuring has been run through a Bootstrap-procedure programmed in Delphi. This procedure determines confidence-intervals for the speed-distribution-curve. Figure 1 shows the graphic output from a Bootstrap-procedure for one of the test-sites in Lund.



The Bootstrap procedure allows determination of confidence intervals both ways in the curve. Above the graph are printed the intervals of confidence, both speed and percentile.

Fig. 1 Graphic output from Bootstrap procedure. Shows the speed-distribution curve for one of the sites measured. Curves displaying confidence intervals are also shown

The Bootstrap-output provides data for analysis of the need for measurement at each site.

The results from the pilot-study sampling are presented in part 6 Results.

5 Illustration

The program emme/2 has been used to illustrate the speed-measures. Emme/2 has got many advantages. One of the biggest is it's ability to present traffic-data. The speed on a street can be displayed with colour-codes for different speed-intervals and/or a bar, parallel to the street, with proportional width to the speed(fig 2). The 85-percentile has been the most studied speed measure in this project. Lately some new measures have been studied, such as the percentage of cars travelling at a greater speed than 30 km/h, and the amount of cars travelling at a greater speed than 30 km/h. Another great advantage is the capability of calculations. These can be made on all or part of the links. A wide range of mathematical and logical functions are available. If emme/2 has already been used for calculating traffic flow, those data can easily be used in speed-flow analysis.

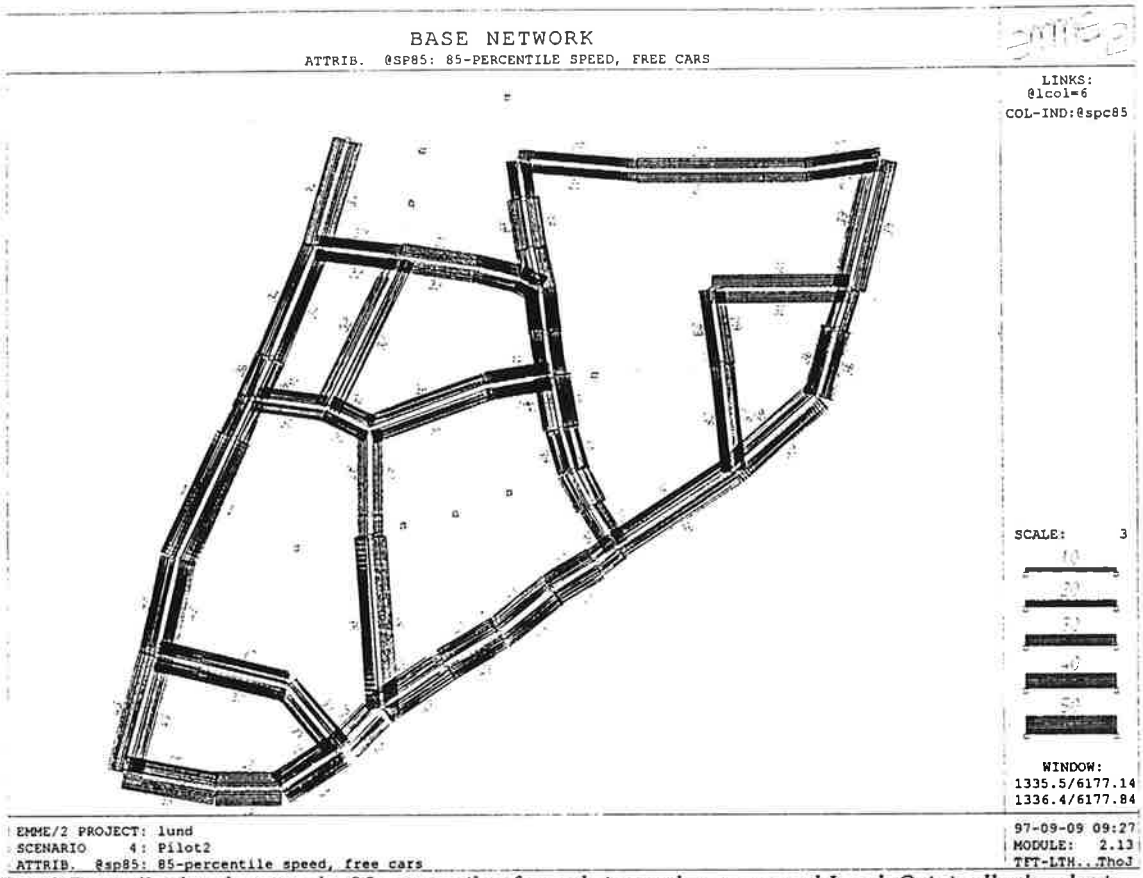


Fig. 2 Emme/2-plot showing the 85-percentile of speeds in south-east central Lund. Originally the plot is also colour coded in intervals of speed

An excel-procedure for transforming the speed-data into emme/2-readable batchfiles has been developed. Thus data is easily transferred from a database to emme/2.

Within the illustration-process it is also possible to show traffic-flows and other traffic data. Emme/2 offers great possibilities to present data area wide. It is however restricted in some ways. It is based on a traffic network illustrated as nodes(crossings or turns) and links(streets). In order to present traffic data you have to have a network to work with. If emme/2 isn't used for other traffic analysis purposes in the area and thus there aren't any existing network available over the area, a network has to be created from scratch. This takes a lot of time and in that case it might be easier using a program that bases its illustration on a scanned map.

6 Results

Throughout the pilot-study, the big question has been: "How many cars do we have to measure at each site in order to get reliable results?". For our purpose, locating streets where 30 km/h wouldn't get compliance, the need for small intervals of confidence aren't all that important. Figure 3 shows the size of confidence-interval for different sizes of samples, 30, 50 & 100 cars. N stands for non-significant results.

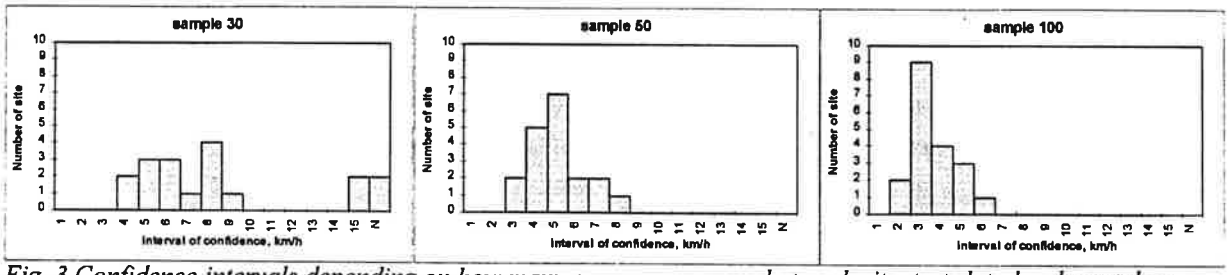


Fig. 3 Confidence intervals depending on how many cars are measured at each site, test-data has been taken from the pilot study in Lund

A sample of 50 cars yields confidence intervals for the 85-percentile of approximately 5 km/h. This is sufficient for our needs, at the same time as less measuring would be ineffective. Most of the time would be used moving from one measuring-site to the other.

Looking at percentage of drivers exceeding 30 km/h

If the aim is still to be the location of trouble spots regarding the 30 km/h speed limit, the need for measurement will vary with speed. Returning to the speed-distribution-curve in Fig. 1, it is easily seen that in the area where we want to be, the top 10 percent, the confidence intervals for speed-exceeding-percent are small. If the speeds are mainly exceeding 30 km/h, there are no pressing need to examine exactly how many percent are driving faster than 30 km/h. Fig. 4 illustrates these confidence intervals for the test-sites.

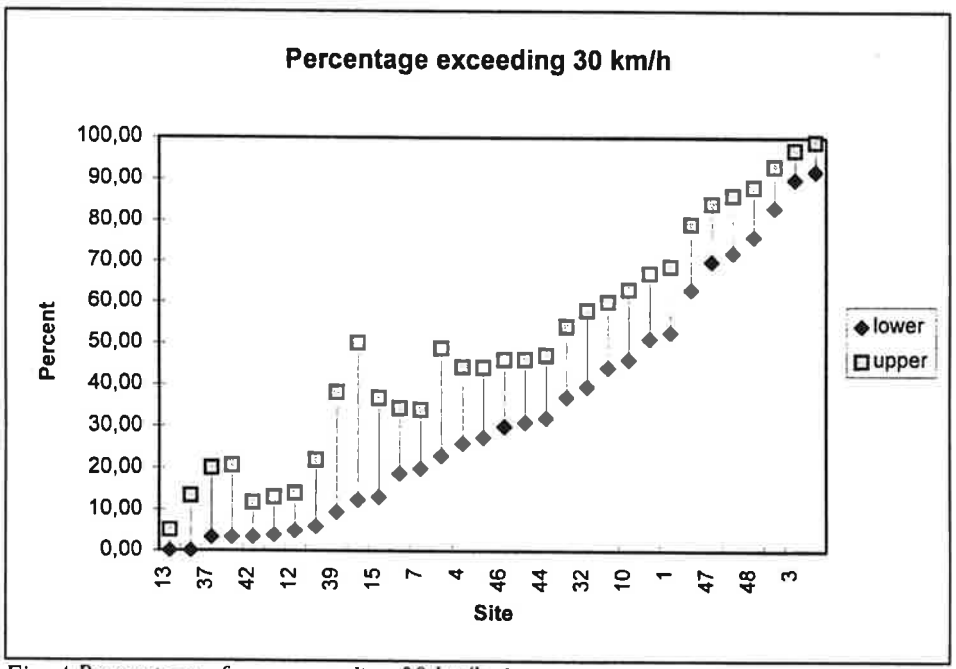


Fig. 4 Percentage of cars exceeding 30 km/h shown as confidence intervals

7 The future

The pilot study has brought us a long way on the road to area wide illustration of car speeds. There are, however, still issues and problems to be looked into.

- **Speed-variance** - How does speed vary with parameters as time, traffic-flow, physical measures of the streets, weather and other sources of variation?
- **The illustration process** - Emme/2 works fine as long as you've got a network to start with. Creating a whole new net takes a lot of time. The search for a system that bases it's presentation upon a scanned map, at the same time as it has got emme/2's advantages with traffic-presentation, goes on.
- **Needs of measuring** - With the new way to look on speeds. Replacing the 85-percentile with percentage of drivers exceeding 30 km/h calls for a revaluation of the need for measurement at each site.
- **Continuous contra discreet measuring** - During the pilot study, measuring has taken place at specific points along a street or at an intersection. Measuring points weren't specifically chosen at places where vulnerable road-users could be expected. The pilot-area is situated in a part of Lund where pedestrians and bicyclists can be expected to cross the streets just about anywhere. At sites with heavy traffic, less centrally situated, it could be assumed that vulnerable road-users locate their crossing to defined places. Therefore it would be interesting to locate these places and illustrate the changes in speed more detailed than was done in the pilot study.

References

Pasanen, E., 1993, The Video Recording of Traffic Accidents, Helsinki city planning department

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EVALUATION OF ACCIDENT BLACK-SPOT REDEVELOPMENT INVESTIGATED AT A SAMPLE OF SITES

1 Introduction

In the Austrian technical guidelines [RVS 1.21, 1990] accident black-spots are defined as road locations (either sections of 250 m length or intersections), where

- 3 injury accidents occur per year, or
- 3 identical injury accidents occur per three years, or
- 5 accidents occur per three years (including damage-only accidents).

Based on this definition, approximately the half of all accidents in large urban areas take place at black-spots. In rural areas, including villages and small towns, about 25 % to 30 % of all road accidents happens at frequent accident locations [e.g. Amt der OÖ-Landesregierung, 1997].

Thus the redevelopment of accident black-spots is one of the most important methods of improving road safety, especially in large urban areas.

Since 1994, the Austrian road traffic regulations require the public road authorities to redevelop frequent accident locations. An often heard counter argument is that there are inadequate public funds available, i. e. it is too expensive to alter a hazardous intersection to meet a high safety standard. And indeed, the argument is understandable. The road authorities or the road maintainers have to pay for road safety measures, but the fruits of this labour accrue to other institutions (insurance companies, health authorities, ...).

However, road safety is a matter of public interest, and so it seems more appropriate to compare the costs of safety measures with savings accruing from the reduction of public accident and, especially, casualty costs.

In the comparisons presented in this paper mainly injury-accidents and casualty costs are considered. Cost figure are rounded to thousand Austrian Schillings (ATS). The Austrian casualty cost values for 1993 of [METELKA, CERWENKA, RIEBESMEIER, 1996] were used:

Per fatality	ATS	11 080 000	(~ECU 850 000)
Per serious casualty	ATS	596 000	(~ECU 46 000)
Per slight casualty	ATS	51 000	(~ECU 3 900)

The examples in the next chapter should give an overview, of how effectively accident black-spot redevelopment can benefit the public economy.

2 Examples of redeveloped accident black-spots in Austria

2.1 Stampfergasse - Wientalstrasse (Vienna)

On reaching Vienna, the eastbound lanes of motorway A1 (*Westautobahn*) turn into the *Wientalstrasse*, a four lane road reducing to three then two lanes. The speed-limit is 70 km/h. The first crossroads is at the traffic-signal controlled *Stampfergasse/Brauhausbrücke* intersection (Figs. 1 and 2); here a third left-turn lane has been added to the *Wientalstrasse*.

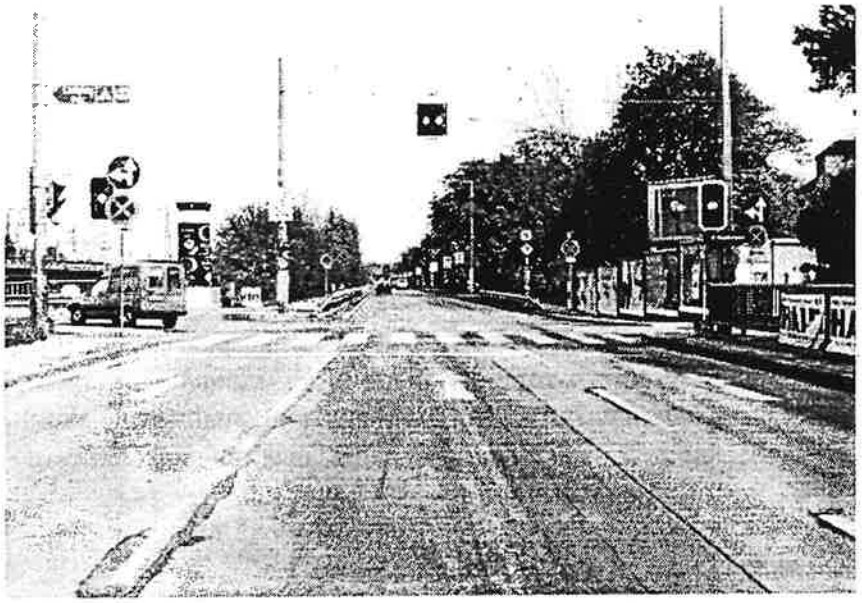


Fig. 1: *Wientalstrasse* when approaching the intersection

Accidents investigated: Right-angled accidents between vehicles in the *Wientalstrasse* and vehicles crossing out of the *Stampfergasse*.

Typical accident circumstances: Vehicles in the *Wientalstrasse* enter the intersection shortly after the beginning of their red phase and collide with vehicles starting out of the *Stampfergasse* on green.

Presumed main accident causes: Drivers in the *Wientalstrasse*: make errors in estimating velocity and stopping distance, caused by poor velocity adaptation coming from the motorway; they miss or see too late the traffic lights changing from green via yellow to red. Drivers in the *Stampfergasse* have no possibility for a visual check before entering the *Wientalstrasse* on green and, therefore, no chance to avoid a collision if a vehicle enters the crossing from the *Wientalstrasse* incorrectly.

Measure implemented (06.1992): One additional second between the end of the green phase in the *Wientalstrasse* and the beginning of green in the *Stampfergasse* (6 seconds instead of 5; the end of yellow in the *Wientalstrasse* and the beginning of combined red/yellow in the *Stampfergasse* now coincide). The measure does not alter the drivers' conditions in the *Wientalstrasse*, but reduces the danger of a typical right-angled accident (Fig. 3).

Cost of measure: ATS 95 000 (8 different traffic signal programs altered).

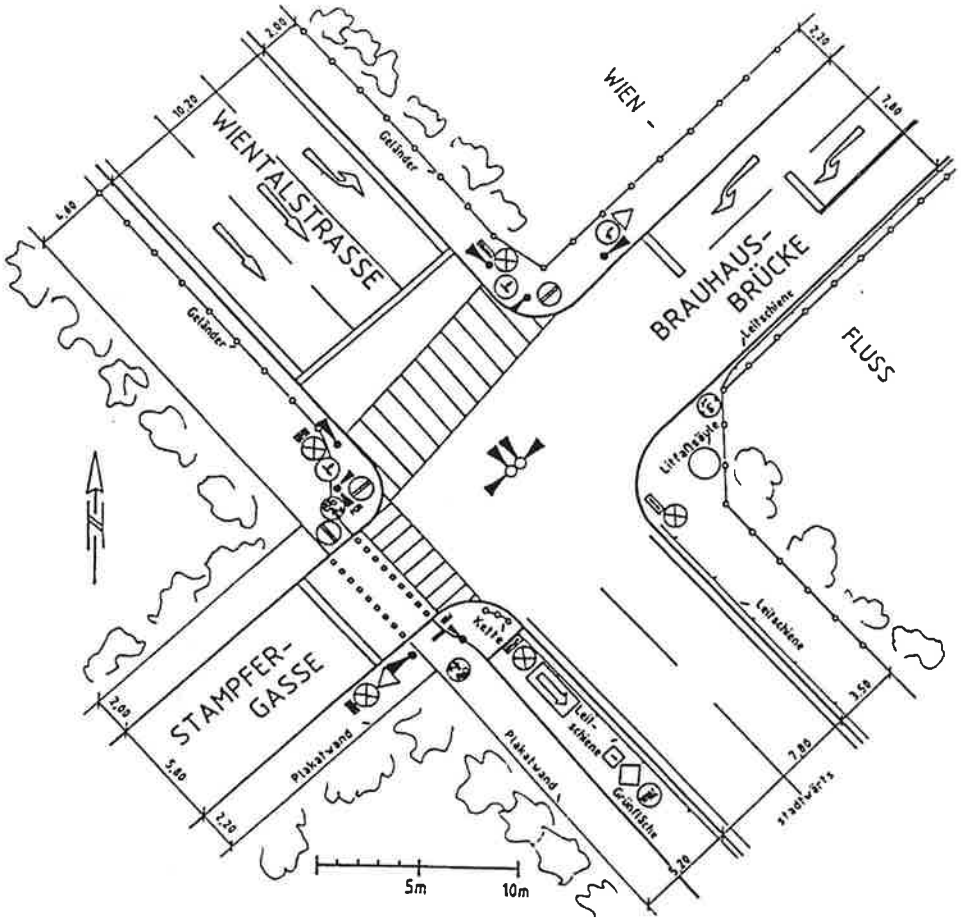


Fig. 2: Intersection *Wientalstrasse - Stampfergasse*; site-sketch

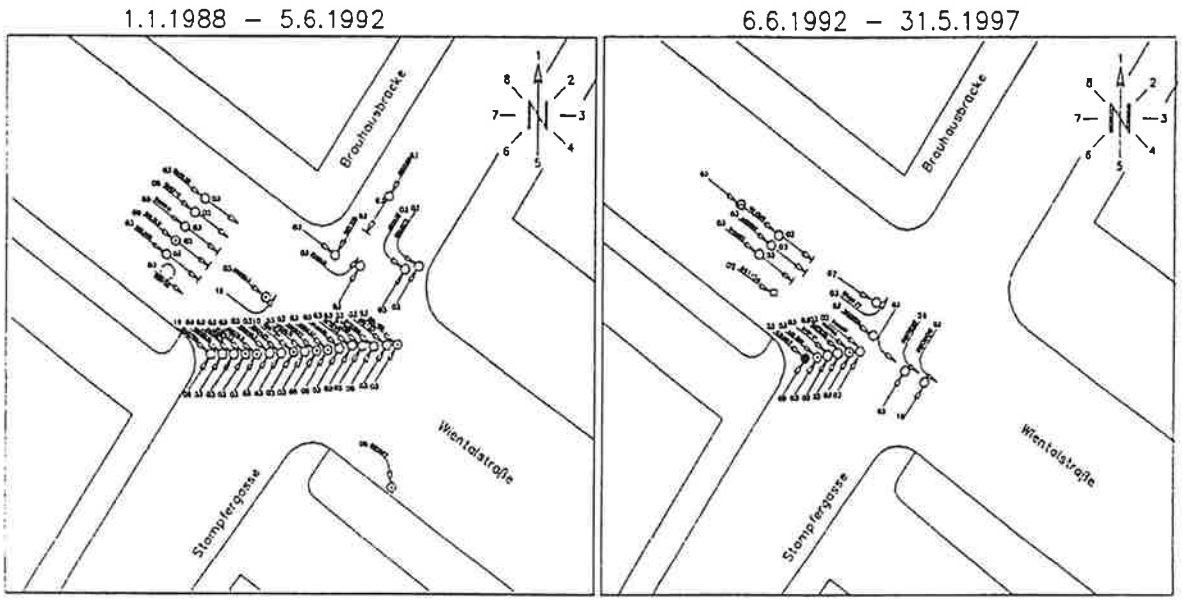


Fig. 3: Investigated collisions in the previous and subsequent period

Table 1: Statistics, only typical right-angled accidents, *Wientalstrasse - Stampfergasse*

		PREVIOUS PERIOD 01.1988 - 05.1992 (53 months)			SUBSEQUENT PERIOD 06.1992 - 05.1997 (60 months)		
total	injury acc.	**17**			**6**		
	casualties	**0** fatal	**8** serious	**19** slight	**1** fatal	**4** serious	**4** slight
	casualty costs	ATS **5 737 000**			ATS **13 668 000**		
per year	injury acc.	**3.8**			**1.2**		
	casualties	**6.1**			**1.8**		
	casualty costs	ATS **1 299 000**			ATS **2 734 000**		

Result: Table 1 shows that the average accident rate as well as the casualties after implementing the measure decreased to one third. The surprising doubling of casualty costs is caused by the one fatality in the subsequent period.

Often it is pure chance, whether a road accident ends with a fatality or a serious casualty. Had the one fatality been a "serious casualty", the subsequent period casualty costs would have decreased from ATS 13 668 000 to ATS 3 184 000 or to ATS 637 000 from ATS 2 734 000 per year. This would be roughly the half of the previous period costs.

The money saved in one single year would be seven times the costs of the measure implemented.

2.2 Beheimgasse - Bergsteiggasse (Vienna)

Both *Beheimgasse* and *Bergsteiggasse* are one-way streets with one lane and with cars parked on both sides (Fig 4). The intersection is located in a typical old Viennese residential area. Traffic in *Bergsteiggasse* takes precedence over traffic in *Beheimgasse* (stop sign).

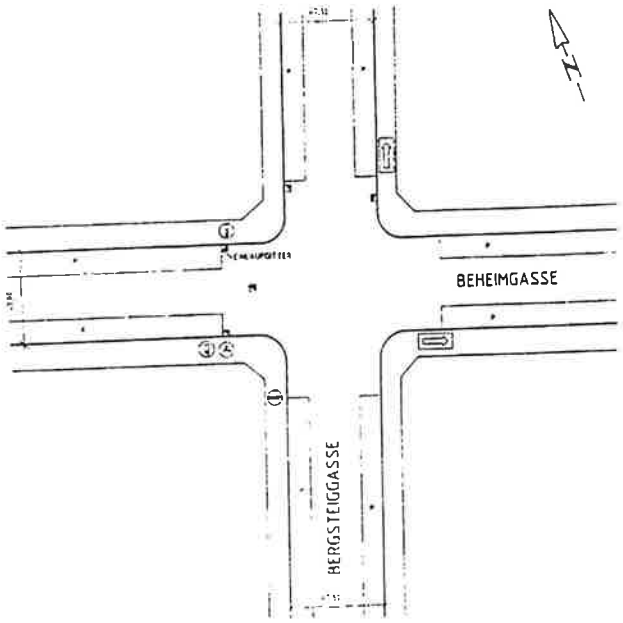


Fig. 4: Intersection *Beheimgasse - Bergsteiggasse*; site-sketch (original situation)

Accidents investigated: Right-angled accidents only.

Typical accident circumstances: Vehicles out of *Beheimgasse* enter the intersection too late ahead of cars approaching in *Bergsteiggasse*.

Presumed main accident causes: Drivers in the *Beheimgasse* may even obey the stop sign and stop but, because of the bad sight conditions, they do not see or see too late cars approaching in the Bergsteiggasse.

Measure implemented (07.1993): The pavement was extended in the important corner of the intersection to improve the sight conditions. The measure does not alter the legal parking conditions, but illegal parking at the junction corner is obviated (Fig. 5).

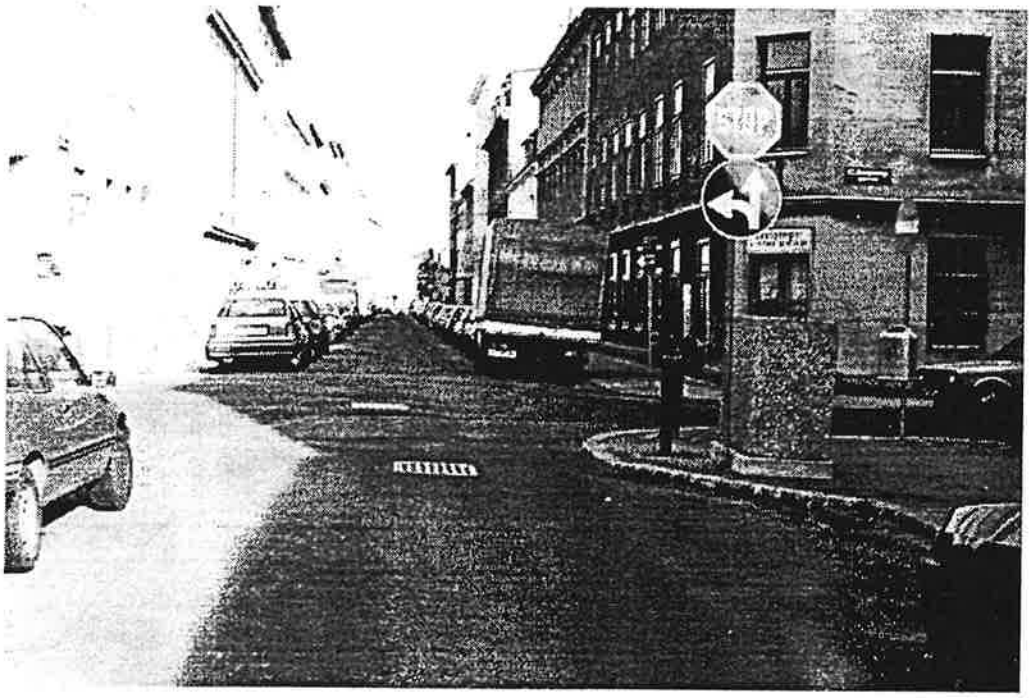


Fig. 5: Intersection *Bergsteiggasse - Beheimgasse* with extended pavement

Cost of measure: ATS 80 000

Table 2: Statistics, right-angled accidents, *Bergsteiggasse - Beheimgasse*

		PREVIOUS PERIOD 01.1990 - 06.1993 (42 months)			**SUBSEQUENT PERIOD** 08.1993 - 04.1997 (45 months)		
total	injury acc.	**4**			**2**		
	casualties	**0** fatal	**1** serious	**7** slight	**0** fatal	**0** serious	**2** slight
	casualty costs	ATS **953 000**			ATS **102 000**		
per year	injury acc.	**1.1**			**0.5**		
	casualties	**2.3**			**0.5**		
	casualty costs	ATS **272 000**			ATS **27 000**		

Result: Though the accident rate at this intersection was not very high before implementing the measure, it reduced during the subsequent period to half and casualties to less than a quarter (Table 2). The average yearly casualty costs now are only 10 % from the costs in the previous period.

cost of implementing the corrective measure (ATS 80 000) would have been amortised within a year. This example shows, that even the rather expensive safety redevelopment of such a small intersection effectively saves public money.

2.3 Schubertring - Fichtegasse (Vienna)

The *Schubertring* is part of the Vienna's famous *Ringstrasse*, a road encompassing 270° of the inner city. It is a one-way street with three lanes. Tram tracks flank the three lanes, with the anticlockwise tram track having a direction counter to the traffic flow. There are service roads on one or both sides.

At the junction of interest, a two-way cycle track is situated between the *Schubertring* and its inner service road (Fig. 6).

The *Fichtegasse* is a side street and crosses the *Schubertring*. Crossing cyclists take precedence over traffic in *Fichtegasse*.

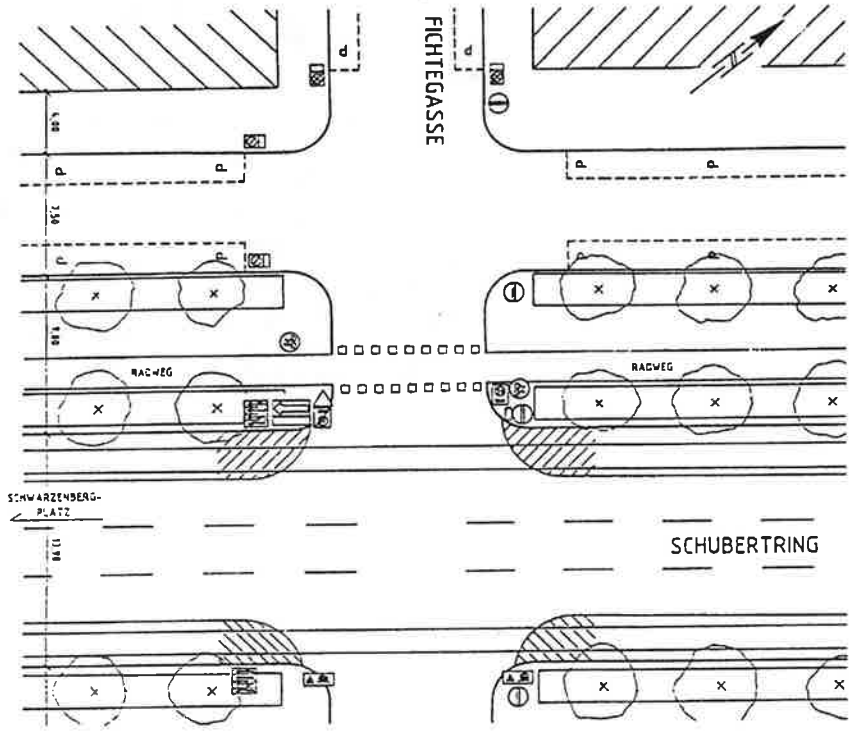


Fig. 6: Intersection *Schubertring - Fichtegasse*; site-sketch (original situation)

Accidents Investigated: Accidents between vehicles in the *Fichtegasse* or vehicles turning from the *Schubertring* into the *Fichtegasse* and cyclists on the cycle track crossing the *Fichtegasse (Fig. 7)*.

Presumed main accident causes: Drivers in the *Fichtegasse* who want to enter *Schubertring*, when approaching, pay attention to traffic on *Schubertring*, which comes from the left, and do not see cyclists coming from the right.

In addition, drivers turning from the *Schubertring* into the *Fichtegasse* often overlook that they have to give way to the cyclists. There is also poor visibility of cyclists, especially, if there are other cars waiting in the *Fichtegasse*.

Cyclists try to cross *Fichtegasse* in front of or between cars waiting to enter *Schubertring*.

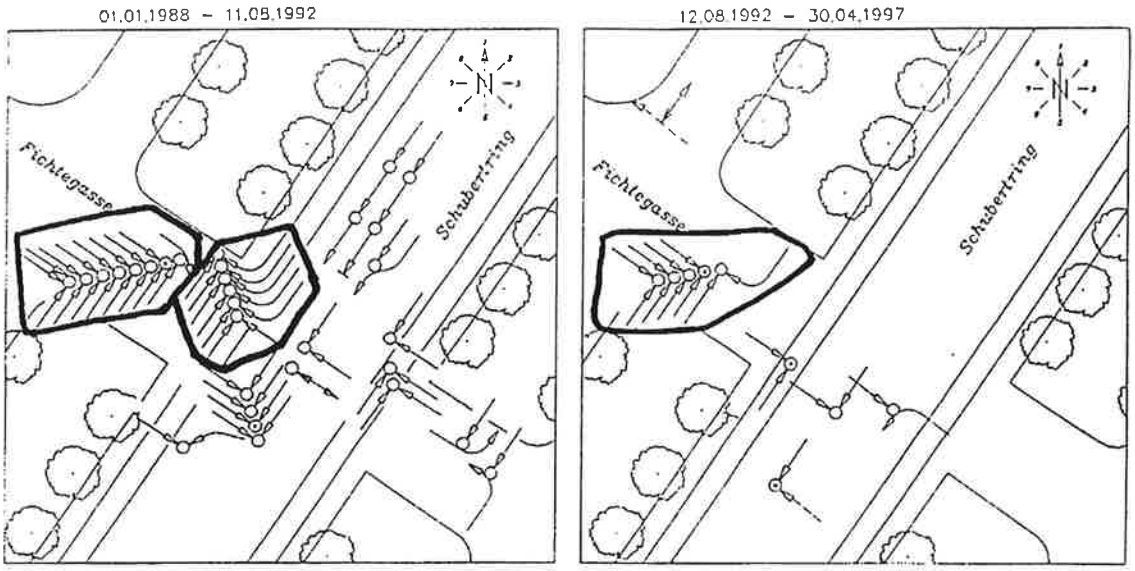


Fig. 7: Accidents with cyclists in the previous and subsequent period

Measure implemented (08.1992): The cycle track was raised (10 cm) and now crosses the *Fichtegasse* on a hump that also incorporates a new pedestrian crossing (Fig. 8). Cars now cross the cycle track at low velocity, and car drivers pay much more attention to cyclists (and pedestrians) than before.

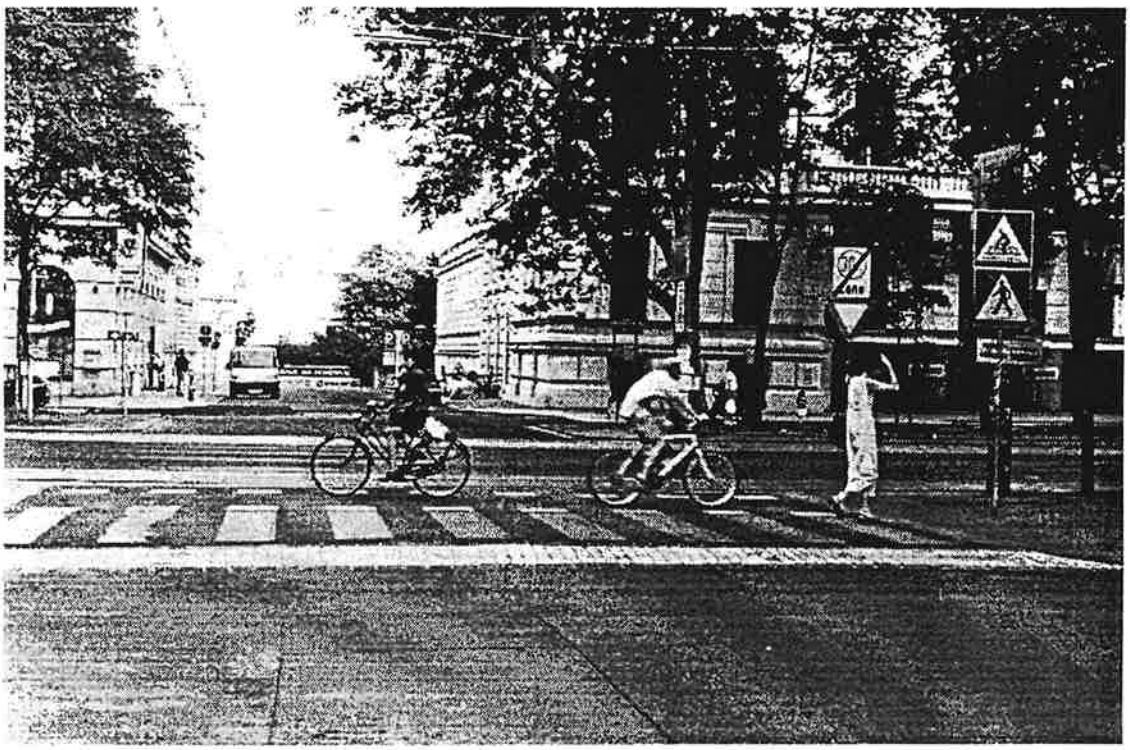


Fig. 8: View from the *Fichtegasse* to *Schubertring*, cyclists and pedestrians crossing on the raised surface

Cost of measure: ATS 150 000

Table 3: Statistics, only accidents with cyclists involved, *Schubertring - Fichtegasse*

		PREVIOUS PERIOD 01.1988 - 07.1992 (55 months)			SUBSEQUENT PERIOD 08.1992 - 04.1997 (57 months)		
total	injury acc.	**14**			**5**		
	casualties	**0** fatal	**2** serious	**12** slight	**0** fatal	**1** serious	**4** slight
	casualty costs	ATS **1 804 000**			ATS **800 000**		
per year	injury acc.	**3.1**			**1.1**		
	casualties	**3.1**			**1.1**		
	casualty costs	ATS **394 000**			ATS **168 000**		

Result: In the subsequent period, as Table 3 shows, the total number of injury accidents and casualties are only about 35 % of those in the previous period. The yearly accident rate as well as the casualty rate and the average yearly casualty costs decreased by about 60 %; the average yearly casualty costs saved are ATS 226 000. Again the costs of the measure were paid of within a year.

2.4 Josefstrasse - Landsbergerstrasse (St.Pölten)

Both *Josefstrasse* and *Landsbergerstrasse* are two-way roads in a residential area near the centre of *St.Pölten* (the capital of Lower Austria, with a population of about 50 000). The crossroads was a large junction with traffic islands and separate lanes for the right-turning traffic. The whole situation was very confusing for drivers crossing (Fig. 9). Traffic in *Josefstrasse* took precedence over traffic in *Landsbergerstrasse* (give-way signs).



Fig. 9: View from the *Landsbergerstrasse* showing bad sight conditions (original situation)

Accidents investigated: All injury accidents at the intersection.

Typical accident circumstances: Mainly right-angled accidents between motor-vehicles, all during daylight.

Presumed main accident causes: Drivers in the *Landsbergerstrasse* did not recognize that they have to give way to traffic in *Josefstrasse*, and entered the intersection without slowing down. Other drivers observed the traffic in the *Josefstrasse*, but missed or saw too late the approaching vehicles.

Measure implemented (06.1994): The intersection was rebuilt as a roundabout (Fig 10).

Cost of measure: ATS 1 885 000

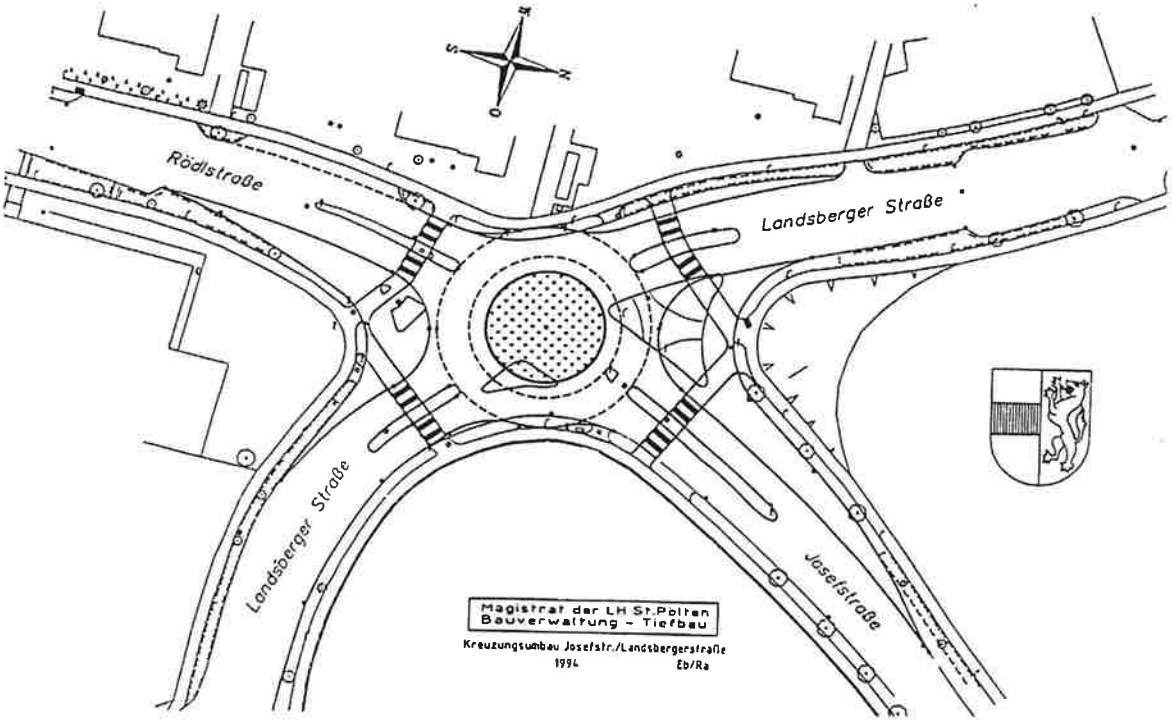


Fig. 10: *Josefstrasse - Landsbegerstrasse*: a roundabout (35 m dia.) built instead of the complex intersection

Table 4: Statistics, all injury accidents, *Josefstrasse - Landsbergerstrasse*

		PREVIOUS PERIOD 01.1992 - 05.1994 (29 months)			**SUBSEQUENT PERIOD** 07.1994 - 12.1996 (30 months)		
total	injury acc.	**8**			**0**		
	casualties	**0** fatal	**2** serious	**6** slight	**0** fatal	**0** serious	**0** slight
	casualty costs	ATS **1 498 000**			**0**		
per year	injury acc.	**3.3**			**0**		
	casualties	**3.3**			**0**		
	casualty costs	ATS **620 000**			**0**		

Result: Even at an intersection with a "medium" accident rate, the construction of a roundabout amortises after approximately 3 years.

2.5 S4 - B50 (Burgenland)

The *S4* is a "Schnellstrasse" (express road, two lanes in each direction with no turning across the oncoming traffic, without a hard-shoulder). It is approximately 20 kilometres long and leads from Lower Austria to Burgenland. For its last several hundred metres it turns into a broad two-way road and leads at right angles (with stop signs) into the federal highway *B50*, also a two-way road.

Accidents investigated: All accidents (including the accidents with damage only).

Typical accident circumstances: Two thirds of the accidents involved cars from the *S4* crossing the *B50* and leaving the road straight ahead at the junction (70 % when the road surface was wet); most others were right-angled impact accidents [SCHANTL 1995].

Presumed main accident causes: Driving along the express road, drivers had problems in realising, that it ended in a T-junction, and noticed too late, that they had to stop at the junction. Drivers coming from the *S4* are affected by velocity adaptation problems: the speed seems lower to them than it really is and, therefore, they fail in estimating the braking distances. In general, drivers tend to approach the junction at too high a velocity.

Measures implemented (07.1992): A give-way sign above the approach lane equipped with solar-energy powered blinking lights was placed 350 m before the junction (Fig. 11).

The surface was milled several times (each slot 2 cm deep, 50 m long, 100 m apart) for some hundreds of metres ahead of the junction to cause a "rumble effect" to alert drivers in time. Near the junction, the entire road was milled to increase the grip of the coarsely textured surface.

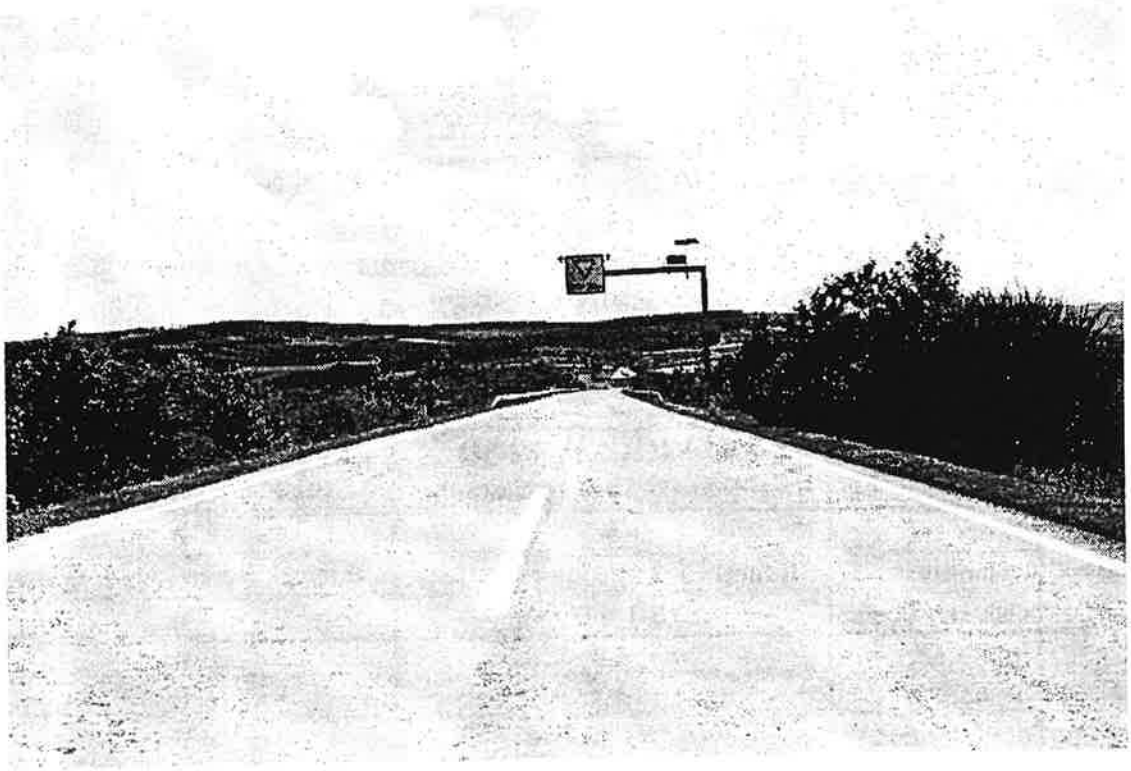


Fig. 11: Measures implemented on the *S4* when approaching the T-junction with the B50: give-way sign equipped with solar-energy powered blinking lights; milled slots at road surface

Cost of measures: ATS 220 000

Table 5: Statistics, all accidents (including the accidents with damage only), *S4 - B50*

		PREVIOUS PERIOD 01.1987 - 06.1992 (66 months)			SUBSEQUENT PERIOD 07.1992 - 06.1995 (36 months)		
total	damage acc.	29 (!)			2		
	injury acc.	2			0		
	casualties	0 fatal	1 serious	6 slight	0 fatal	0 serious	0 slight
	casualty costs	ATS 902 000			0		
per year	damage acc.	5.3			0.7		
	injury acc.	0.4			0		
	casualties	1.3			0		
	casualty costs	ATS 164 000			0		

Result: Of interest is the large number of damage-only accidents and, especially, the extreme reduction after implementing the measures by nearly 90 % (Table 5, Fig. 12). The measure costs were totally amortised within the subsequent 18 month (and that despite car damage costs and the costs of some dozen destroyed road signs are not considered).

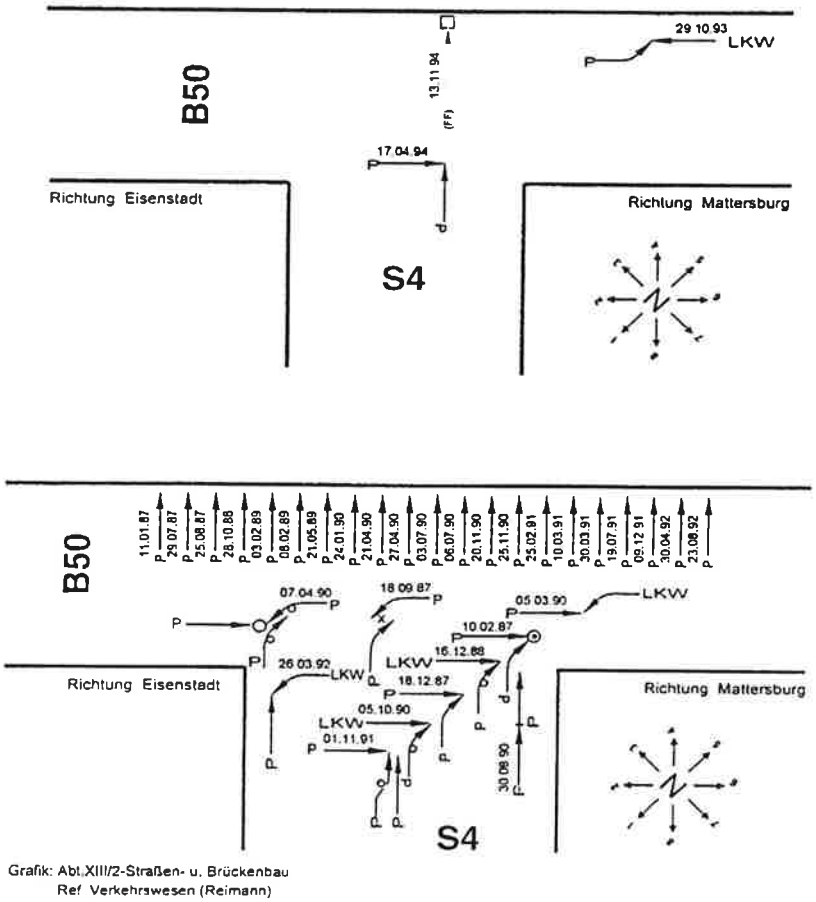


Fig. 12: Investigated collisions in the previous and subsequent period

3 Conclusions

Over the past years, many Austrian accident black-spots have been redeveloped. Because most resulted in positive effects, there was little difficulty in selecting examples.

Accident black-spot redevelopment is a very effective measure to lower the peak of the "road accident mountain". It decreases both accident rates and casualties. And, as shown, it benefits national economy, because the public money saved as a result of the reduction in casualties is normally several times the costs of the corrective measures taken.

Sources:

Amt der OÖ-Landesregierung: Oberösterreich - Unfallstatistik und Unfallanalyse (Office of the Government of Federal State of Upper Austria, Accident statistics and analyses) Linz 1996

METELKA M., P. CERWENKA, B. RIEBESMEIER: Österreichische Unfallkosten- und Verkehrssicherheitsrechnung 1993 (Austrian accident costs and traffic safety calculation for 1993), vorläufiger Endbericht Modul 1 + 2, Wien 1996

SCHANTL K.: B50 Burgenland Straße; Kreuzung mit Zubringer S4 - Unfallhäufungsstelle, Sanierung: Vorher / Nachher-Untersuchung (B50/S4 accident investigation expert report), Amt der Burgenländischen Landesregierung (Office of the Government of Federal State of Burgenland), Eisenstadt 1995

RVS 1.21: Verkehrssicherheit, Verkehrssicherheitsuntersuchung.
Richtlinien und Vorschriften für den Straßenbau, Forschungsgesellschaft für das Verkehrs- und Straßenwesen (FVS) (Traffic safety studies, guidance and regulations for road engineering), Wien 1990

Quantitative Expert Judgement Models
A New Tool to Estimate the Effect of Countermeasures

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Abstract

A new tool to estimate the effect of countermeasures is proposed. The effect of traffic safety countermeasures are assessed using a risk index model. The model describes the dependence of risk on various attributes in a multiplicative way, which makes it possible to analyze the impact of different factors separately. Further, expert judgments are incorporated into the analysis by a Bayesian error model. The final risk estimates are determined by Monte-Carlo simulation.

The model was applied to assess the safety effect of elevating a bicycle crossing, causing car speeds to be reduced and bicycle speeds to be increased. Before the implementations, bicyclists were riding on conventional bicycle crossings. It seems as if the positive effect on collision risk caused by a reduction in car speeds was balanced by the increased bicycle speeds, so that the combined effect was plus minus zero. However, the safety per bicyclist was improved by approximately 20% due to the increase in bicycle flow. Some future development work is suggested, and pros and cons with the used methodology are discussed. The most crucial parameter to be added is probably a model describing the interaction between motorists and bicyclists, for example, how risk is influenced by the lateral position of the bicyclist in relation to the motorist. The interaction is probably optimal when both groups ride in the roadway.

1. Purpose and Methods

An eleven-page survey was sent to 22 experts on bicyclists' safety. Planners as well as researchers from thirteen countries were included. In general, we had no prior knowledge of what answers could be expected from a certain expert. We got a total of thirteen answers: Four from the Nordic countries (two from Sweden, one from Denmark and one from Finland), four from other European countries (one from Austria, one from Great Britain, and two from the Netherlands), one from Canada, two from the U.S., and two from Australia.

The velocity of bicycle traffic, as well as various types of interactions, such as stopping behavior, was studied with the help of video recordings from four junctions before and after reconstruction. The speeds were measured for turning, free-moving motor vehicles at the point of potential conflict with bicyclists. Measured speed data together with experts' assessments of relations between speed and risk of collision as well as between speed and injury risk were input in a "Quantitative Expert Judgment Model."

The Quantitative Expert Judgment Model consists of a risk index model, an expert assessment model, and a risk attribute model. The risk index model defines the measure for risk and describes the dependence of risk on the attributes and parameters of the model. Here, the *risk index model* is a multiplicative attribute model, in which the effect of each attribute on risk may be evaluated separately. According to the risk index model, the total risk index is the product of risk indices corresponding to the attributes. The attributes are factors determining the risk. In this case, chosen attributes are the speeds of the vehicles and bicycles. Here, the risk index is not interpreted in a probabilistic way, but it may be directly connected to the accident frequency or other statistical measure. The *expert assessment model* is used for incorporating the assessments made by the experts into the quantitative risk evaluation. We adopt the additive or multiplicative error models (Mosleh & Apostolakis, 1984). Depending on the case, also other types of models may be used (Pulkkinen, 1994). The *attribute model* describes the statistical properties of the attributes on which the risk depends. In a typical situation, the attributes may vary statistically, and they are described by suitable probability distributions. The estimation of these distributions is based on the measurements. A Bayesian approach is applied in the estimation of distributions and the analysis of expert judgments.

Since the parameters and attributes of the models are random variables, also the risk index becomes a random variable. Thus, the risk index is characterized by its probability distribution. The risk index depends on the attributes and parameters in a rather complex way, and the probability distribution cannot be determined without approximate techniques. Here we apply Monte-Carlo simulation.

This paper gives one example showing the advantages and possibilities concerning the use of quantitative risk models in traffic safety. For detailed information about the theoretical background see Pulkkinen & Leden (1997).

2. Illustrative example

We apply the model on an example, in which the attributes are the car speed and the bicycle speed. The model describes the combined effect of these attributes on collision risk.

The experts were asked to draw curves representing the relative risk of collisions between a bicyclist and a right-turning car when the initial speed of the car and the speed of the bicyclist were varied. The experts were also asked to assess the relative injury risk of the bicyclist for different initial speeds of the right-turning car. In the first example here, we will use the

information concerning collision risk. In the second example, we will use the information concerning injury risk.

Figure 1 shows a somewhat simplified form of the original curves, describing the relationship between vehicle speed and risk of collision (assuming risk is 1 when speed prior to the evasive action is 25 km/h), as drawn by the experts.

We assume that the relative risk curves follow an exponential model, i.e.

$$r_i(x_i) = \exp\left[\alpha_i(x_i - x_i^{ref})\right], \qquad (1)$$

in which x_i is the value of the attribute i, $i=1,2$, x_i^{ref} is the reference value (with respect to which the relative risk is evaluated), and α_i is the risk coefficient for the attribute x_i.

In case of the vehicle speed (Figure 1) , the reference speed was 25 km/h. Based on the relative risk curve given by the expert j, we determine the expert's estimate of the risk coefficient, α_{ij}, by fitting the exponential curve to the expert's curve. An example of a relative risk curve and the fitted exponential curve is given in Figure 2.

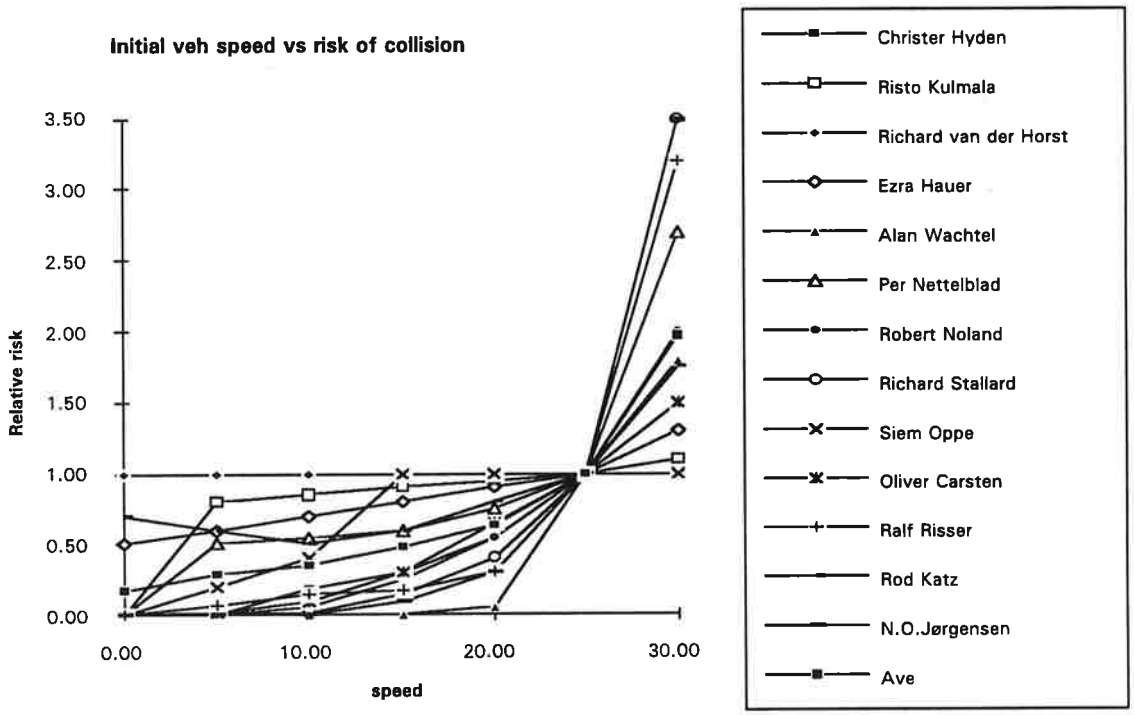


Figure 1 Relationships between vehicle speed and risk of collision, as drawn by experts but shown in a somewhat simplified form (assuming risk is 1 when speed prior to the evasive action is 25 km/h).

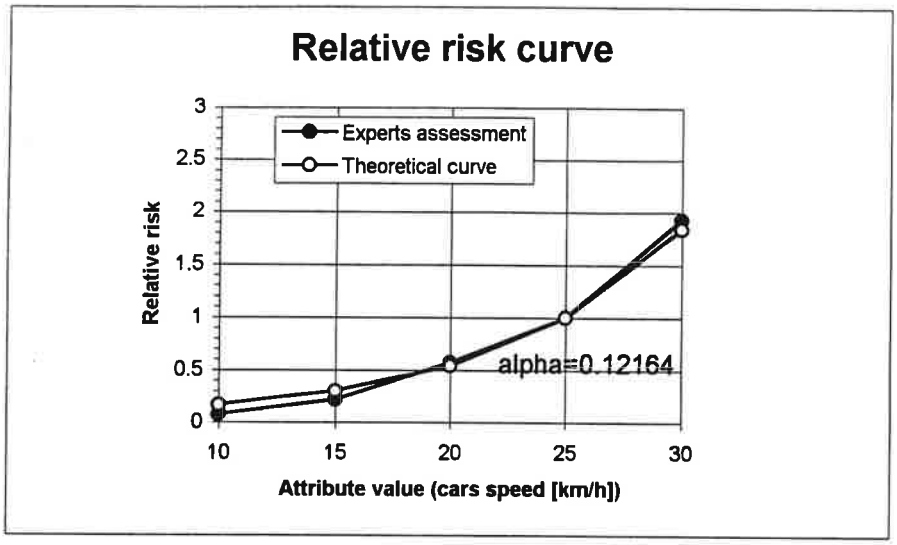


Figure 2. The relative risk curve given by an expert.

The experts' estimates, α_{ij} ,$j = 1,...,12$ evaluated on the basis of relative risk curves (Figure 2) are shown in Table 1. The experts' estimates are combined by using a Bayesian model. We assume, that the experts' estimates, α_{ij}, are related to the true risk coefficient in a multiplicative way, i.e.

$$\alpha_{ij} = \alpha_i \varepsilon_{ij}, \tag{2}$$

where ε_{ij} is the relative random error of the estimate of the j^{th} expert. We furthermore assume that the prior distribution of the risk coefficient is lognormal, $\alpha_i \sim LN(\mu_i, \sigma_i^2)$, and that the relative errors also follow a lognormal distribution, $\varepsilon_{ij} \sim LN(0, \sigma_{ij}^2)$. Finally, by assuming that the relative errors of the experts' estimates are independent, we obtain a lognormal posterior distribution for the risk coefficient. For the risk coefficient corresponding to the vehicle speed we obtain the lognormal posterior distribution, $\alpha_i \sim LN(-2.702, 0.826)$, the density function of which is shown in Figure 3.

Table 1. Experts' estimates of parameters.

Expert, j	α_{ij}
1	0.000
2	0.186
3	0.078
4	0.085
5	0.122
6	0.213
7	0.197
8	0.033
9	0.092
10	0.261
11	0.131
12	0.00

The uncertainty of α_i has naturally an impact on the (posterior) relative risk index. We demonstrate this in Figure 4, where the posterior fractiles of the relative risk curves are presented.

The posterior relative risk curves are still rather uncertain: for example, the *90%* probability interval for the relative risk of the car speed at *35 km/h* is approximately *(1,20)*. This means that the information from the expert assessments is not very strong, which is a rather realistic result. Although it is not an easy task to specify the expert judgment model, especially the variance of error term ε_{ij}, the expert model applied here seems to give qualitatively reasonable results.

To compare risks of two situations one must also determine the predictive distributions of attributes. Therefore we calculated the predictive distributions of car and bicycle speeds before and after the intervention. They are shown in Figure 5 and 6 respectively. The tail with high speeds of the distribution of car speeds after change are due to a small number of measurements.

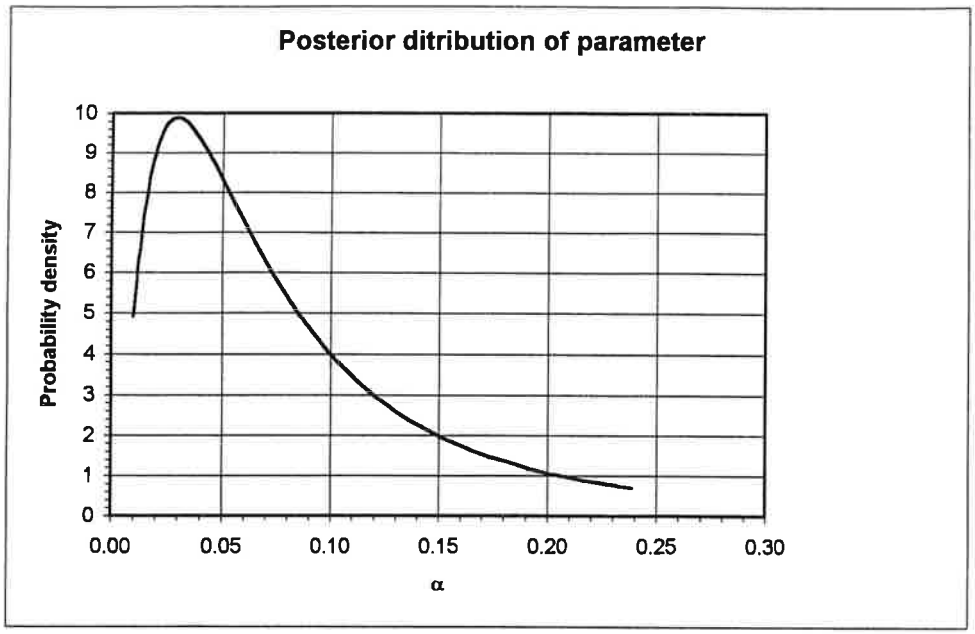


Figure 3. The posterior probability density of α_i.

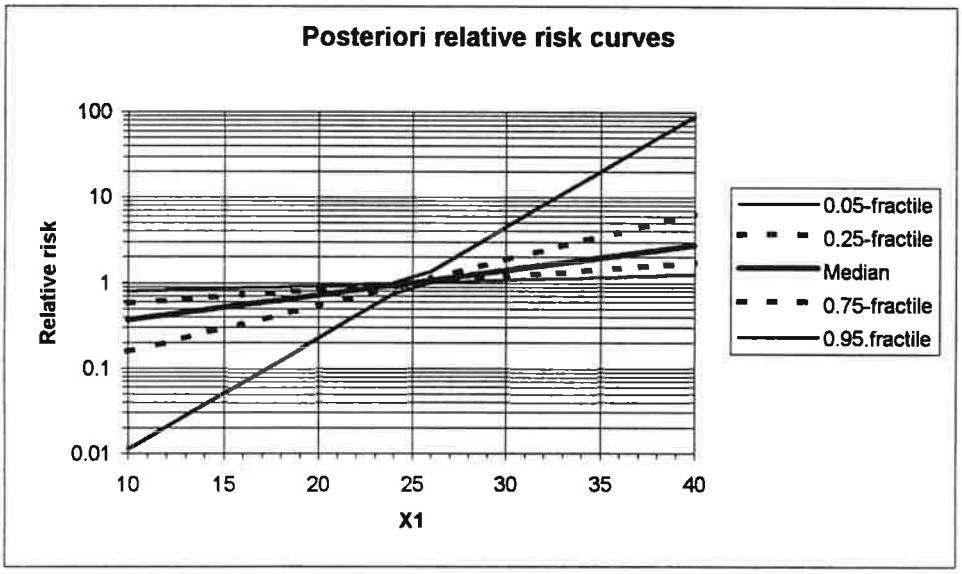


Figure 4. The posterior fractiles of relative risk curves for different speeds (km/h).

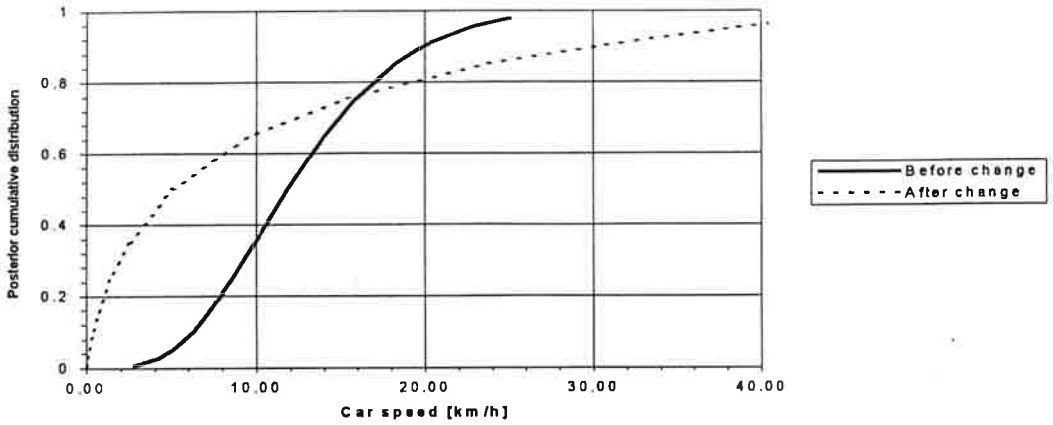


Figure 5. The predictive distributions of speeds of right turning cars. Empirical data from the intersection of Första LFånggatan and Sänkverksgatan.

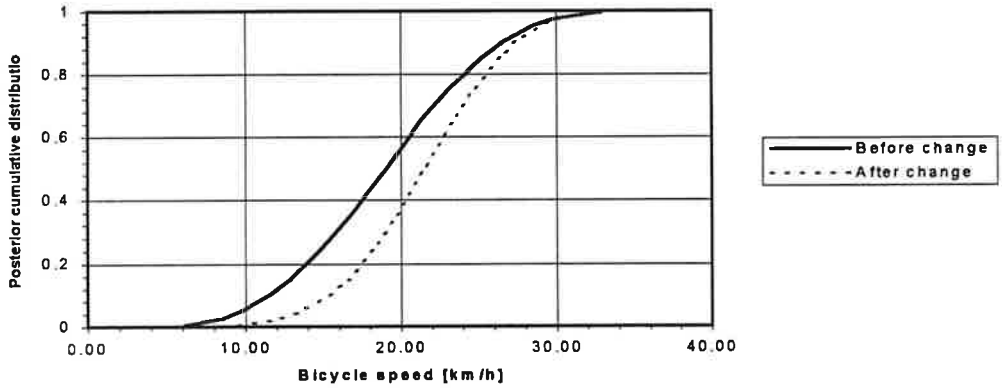


Figure 6. The predictive distributions of speeds of bicyclists. Empirical data from the intersection of Första Långgatan and Sänkverksgatan.

As empirical data also show, right-turning-car speeds were reduced and bicycle speeds were increased. The mean speed for right-turning cars into Sänkverksgatan was reduced from 12.2 to 7.4 km/h and the mean speed for bicyclists was increased from 5.3 to 6.0 m/s, *i.e.* from 19.1 to 21.6 km/h. The uncertainty in the posterior cumulative distribution after change is due to the few observations of car-speed measurements after the intervention.

Next step is to calculate the distributions of the ratio of risk indices. Figure 7 shows the posterior distribution of the ratio of risk indices based on right-turning-car speeds before and after the intervention. The median of the ratio is 0.76, indicating that the risk is higher before the change.

Figure 8 shows the posterior distribution of the ratio of risk indices based on bicycle speeds before and after the intervention. The median of the risk ratio is 1.4, indicating that the risk is higher after the change.

Figure 9 shows the combined risk indices resulting from decreasing car speeds and increasing bicycle speeds. The median of the risk indices are 0.9, indicating a small risk decrease. Roughly speaking, it seems that the positive effect on traffic safety obtained by the reduced car speeds is balanced by the increased bicycle speeds, so that the combined effect is plus minus zero.

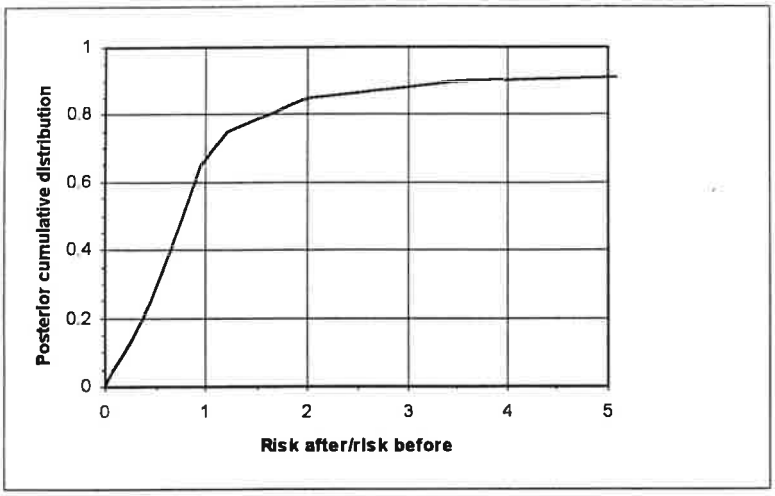


Figure 7. The posterior distribution of the ratio of collision risk indices based on right-turning-car speeds.

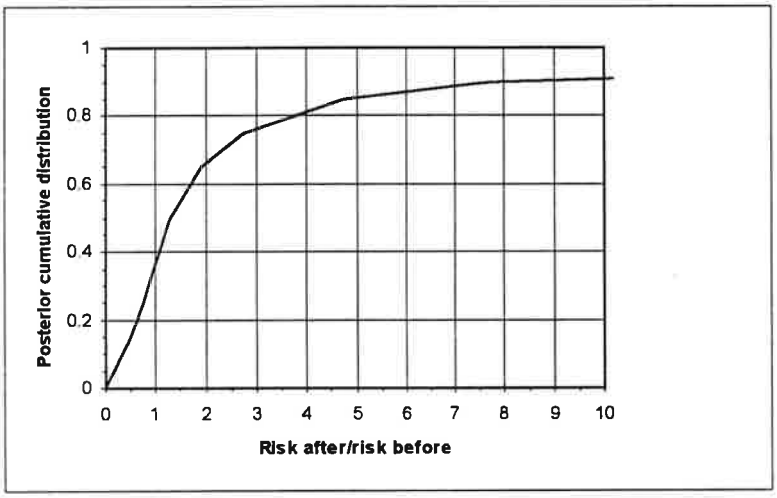


Figure 8. The posterior distribution of the ratio of collision risk indices based on bicycle speeds changes.

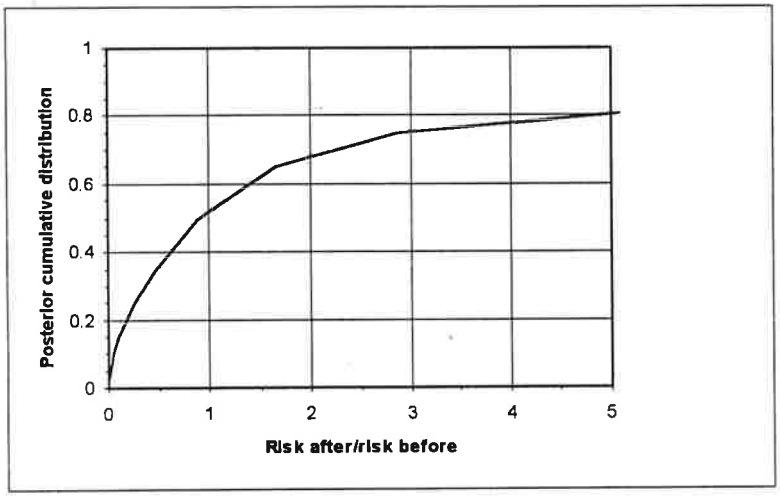


Figure 9. The posterior distribution of the combined collision risks indices based on car and bicycle speed changes.

For the approximation of the results from the Quantitative Expert Judgment Model to a probability density function PDF we used the lognormal distribution:

$$f(\theta|\mu,\sigma^2)=\frac{1}{\theta\sigma\sqrt{2\pi}}\exp\left[-\frac{(\ln(\theta)-\mu)^2}{2\sigma^2}\right] \quad (3)$$

in which μ and σ are the parameters. The reason for using lognormal distribution is that it fits well with the results of Monte-Carlo simulation. Another possibility would have been to use the empirical density based on the simulation results. The estimated PDF is shown i Figure 10. The curve is flat indicating that predictions are far from precise. The main reason for this is that the two simulated phenomena are canceling out each other.

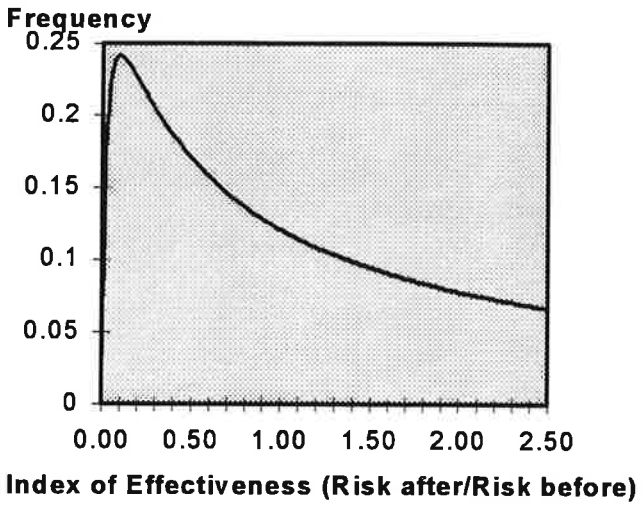


Figure 10. Distribution of the risk index according to the Quantitative Expert Judgment Model estimating the effect of elevating a bicycle crossing. Estimated parameters for the lognormal distribution: -0.1237 and 1.74.

When asked directly about the effect of raising the path 10 cm and paving it red, the experts estimated, on average, a 30% improvement in safety. The average for q was estimated to be 0.71 with a standard deviation of 0.28. As prior function describing the opinions of experts on the effect of the measure, we chose the Gamma distribution with density function:

$$f(\theta|q,\alpha)=\frac{1}{\Gamma(q)\alpha^q}\theta^{q-1}\exp[-\theta/\alpha] \quad (4)$$

where θ is the effect of the measure, $\Gamma(\cdot)$ is the Gamma function, while $q > 0$ and $\alpha > 0$ are the parameters of the distribution. In order to estimate q and a, the moment method is applied, i.e. the theoretical mean value and variance

$$E[\theta] = q\alpha \qquad (5)$$
$$\text{var}[\theta] = q\alpha^2$$

are assumed to be equal to the mean and variance of the sample of the interviewed experts.

The estimated prior distribution of the risk index is shown in Figure11. However, it has to be kept in mind that the experts were told that all other external factors, including bicycle flow volumes, were to be considered unchanged. We have estimated the effect of the observed increase in bicycle flow below.

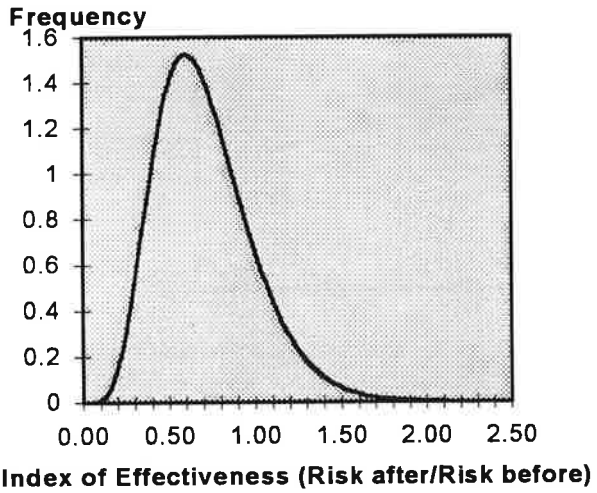


Figure 11. Distribution of the risk index according to the experts' estimates of the effect of elevating a bicycle crossing. Estimated parameters for the gamma distribution: 6.43 and 0.11.

3. Effect on Bicycle Volumes and the Safety Effect of Changes in Volume

Bicycle flows increased on one of the streets by 75 % on one side and by 79 % on the other side, and by 100% on the second of the two streets where extensive measurements were taken before and after the reconstruction. Measurements of bicycle flows on the two control sections

indicate a general growth in bicycle flows of around 20%. The extra increase on our experimental sections would then be at least 50%, the result of better layout.

An analysis of the relationship between bicycle flow and the number of reported accidents in the experimental area shows that the relative risk—when risk is defined as the number of expected (reported) accidents per passing bicyclist—decreases with increasing bicycle flow (Figure 12). A 50% increase of the flow reduces the relative risk by about 24%. However, the increase of the bicycle flow means that the total number of reported bicycle accidents would be expected to increase by about 15% (1.5 x (1 – 0.24) = 1.14). If the bicycle flow is doubled, e.g., from 50 to 100 bicyclists per hour, the relative risk would be reduced by 38% while the total number of reported accidents would grow by about 25% (2 x (1 – 0.38) = 1.24).

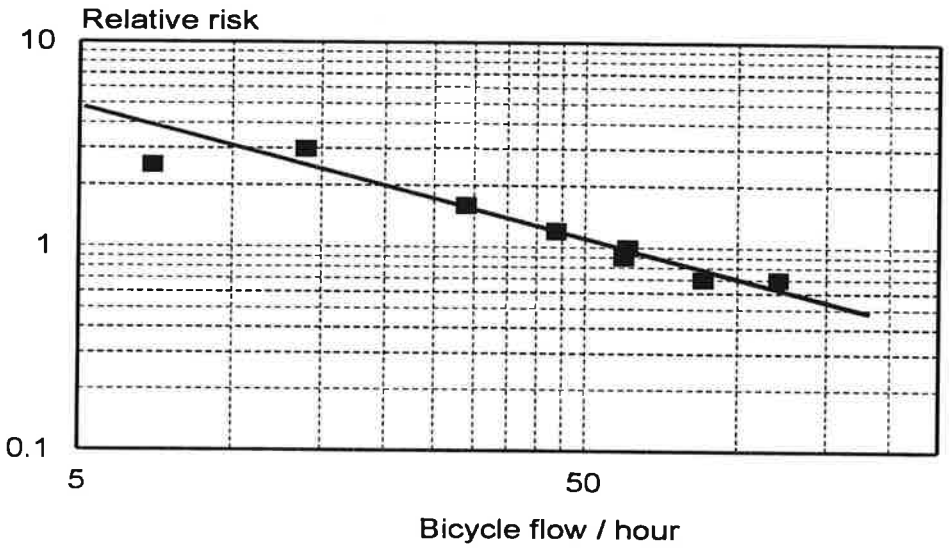


Figure 12. How the relative risk of a bicycle accident is affected by the bicycle flow. Logarithmic scale.

4. Concluding remarks

The experts' assessments of the risk were made separately for each attribute. The exponential model was used to approximate the assessments of the experts. The experts were asked to give their opinions in the form of relative risk curves, from which the parameters of the exponential distribution were estimated. Based on the experts' estimates, we determined the posterior distribution of the parameter by using a Bayesian multiplicative (or additive) error model. Although there are obvious difficulties in the specification of the expert assessment model, the approach is transparent and reproducible. Further, it is possible to make sensitivity studies with respect to the specification of the model. In our case study, we assumed that the relative risk curves are exponential. One problematic issue of the model is that the relative risk curves given by the experts do not necessarily correspond to the exponential risk curve. This problem may

be overcome either by restricting the experts' curves beforehand to the class of exponential curves or by allowing also other type of curves such as logistic curves and power curves. The latter would probably lead to calculation problems due to the increased number of parameters. It is also possible that the calibration of experts leads to more consistent assessments.

Another problem is the specification of the prior distributions for the risk parameters. A solution to this is to use as flat a distribution as possible. However, this would lead to distributions with large σ (the variance of Gaussian distribution behind the models) in the additive as well as the multiplicative error models. Further, it is very difficult to specify the distribution of error of the experts' estimates. The variance of this distribution describes the experts' ability to produce good estimates. We recommend sensitivity analyses and empirical studies to evaluate this issue.

The quantitative approach discussed here gives useful results for comparison of risk in various situations. The expert judgments are treated in a consistent way and the uncertainties are interpreted in a probabilistic way. The uncertainty of expert judgments is propagated through the model and the final risk comparisons are presented in the form of probability distributions.

The quantitative approach described here is in common use in the field of technological risk assessment (Pulkkinen, 1994). The methodology is rather mature. On the another hand, the use of quantitative arguments cannot be avoided in decision making related to traffic safety, especially when risks and cost of different designs are compared. Although many of the arguments are based on experts' opinions, it is possible to code them into a quantitative format by applying the methodology of this paper. Due to a mathematical formulation, the analysis becomes transparent and the factors having impact on risk can be treated analytically.

The exact magnitude of the improvement of bicyclists' safety can at this point not be established. Sufficient accident data is not available. The direct estimate by experts indicate that the safety is significantly improved. However, neither bicyclists nor experts may have taken into consideration the fact that bicyclists' speeds were increased as a result of the reconstruction. If experts were informed about that fact, they may very well have given more conservative answers. Also, bicyclists may consider their speed to be of little importance with respect to safety, whereas our expert survey clearly shows that 'experts' are of the opposite opinion. We are bound to believe that the experts are correct in this assessment. Obviously, there are many other factors than speed that also influence the risk of injury, e.g., whether the bicyclist is wearing a helmet, whether motorists yield when supposed to, but a bicyclist's speed certainly can influence his/her ability to take evasive action when needed.

The accuracy of our expert judgment model is not sufficiently high for drawing any firm conclusions. But, the most interesting observation from this model is not the accuracy of the estimate but the fact that the model predicts less of an improvement than direct estimates do. Future development work seems to be promising. The most crucial parameter to be included is probably a model describing the interaction between motorists and bicyclists, for example, how

risk is influenced by the lateral position of the bicyclist in relation to the motorist. The interaction is probably at its best when both groups ride in the roadway.

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References

Mosleh, A., Apostolakis, G. 1984. Models for the use of expert opinions. In: Waller, R.A., Covello, V.T (eds.), Low-Probability, High-Consequence Risk Analysis. 107-124.

Pulkkinen, U & Leden, L., 1997. Application of a Quantitative Expert Judgement Model in Traffic Safety Analysis - a Methodological Experiment. Paper presented at the ICTCT meeting in Paris 1995. (to be published in Vienna 1996)

Pulkkinen, U. 1994. Statistical models for expert judgement and wear prediction. VTT Publications 181. Technical Research Centre of Finland, Espoo. 65 p. + app. 80 p.

6. SAFETY STRATEGIES

Chairperson: Irit Hocherman

• **Methods for designing integrated road safety programmes: Some reflections based on the work carried out in Estonia.** MUHLRAD Nicole, INRETS, Arcueil, France .

• **The Road Traffic Accident Situation in Ghana.** AFUKAAR Kwaku Francis, Building and Road Research Institute, University of Kumasi, Ghana

• **A study of pedestrian activity and accident risk: Implications for road safety policy.** WARD Heather, Centre for Transport Studies, University College London, UK

• **On a Partially New Approach towards Traffic Planning and Street Design in Sweden.** WRAMBORG Per, SNRA, Borlänge, Sweden

• **Urban Planning and Traffic Safety.** KELCEC-SUHOVEC Stjepan, City Bureau for Development Planning and Environmental Prot., Zagreb, Croatia

• **Can one make walking and cycling more attractive without causing safety problems?** RISSER Ralf, FACTUM, Vienna, Austria

• **Simulation of "Driver-Vehicle-Road-Environment" Systems.** YERYOMIN Valeri, Moscow State Automobile & Highway Inst., Moscow, Russia

Methods for designing integrated road safety programmes: some reflections based on the work carried out in Estonia

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Based on work carried out with
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Introduction

A large number of countries in the world are now facing a sudden and serious growth in road accidents, related to rapid changes in motorisation volumes and patterns. This is particularly the case in Eastern European countries, where private car ownership has been soaring while it was, until the late 80's, reserved to a happy few. As road safety policies now address a population of drivers representative of a much larger share of society than before, they need to be designed in a radically different way and findings of past research into accident causation and road user behaviour are bound to be obsolete.

In such countries, researchers (and other road safety professionals) trained in parts of the world with a long history of road safety work are often called to help design proposals for integrated road safety programmes, usually at the national level, sometimes at the regional or local ones. In most cases, the proposals are seen as urgent by the decision-makers as the accident situation is worsening fast. Researchers thus act as « experts », which means that they are supposed to apply an accepted methodology to whatever data is readily available and have no time to perform field studies, even less research. To make matters worse, the decision-makers, whether members of the national administration or Parliament of the country or representatives of the sponsors, donors or money-lenders (as for example the World Bank or the European Union programmes), are usually unfamiliar with the nature of the accident phenomenon and with road safety methodologies, and their demands, drafted as « terms of reference », may be totally inadequate in view of the time and technical resources available.

Why should researchers try to respond to such demands ? Clearly, at a time when funding for research is dwindling in many Western European countries, undertaking work as experts may add a few cherries on the cake. But there are more positive reasons for it: it is interesting for validation purposes to reflect on technology transfer and to apply one's methods or findings to a traffic and social situation different of one's own; also, road safety researchers may have more adequate knowledge and more scientific scruples in

performing the requested task than other experts who will anyway submit proposals as soon as terms of reference are issued.

A project carried out in Estonia in 1996-97, within the PHARE programme of the EU, to design a national road safety programme for the short, the medium and the long-term is a good example to illustrate methodological problems and difficulties encountered by researchers and road safety professionals, as well as the experience that can be gained from this kind of work. The project was performed by a joint team from Viatek (Finland) and BCEOM (France), including experts from Inrets (France) and Stratum (Estonia) (Viatek-BCEOM, 1997).

The demand and how it was interpreted

The aim of the project was to produce alternate scenarios for national road safety policies in the short, medium and long terms, and to evaluate them *a priori* on a cost efficiency basis. The working team was requested to propose five different options (i.e. fifteen time-related scenarios) in relation to problems recognized as major « issues ». Unfortunately, different sets of issues were mentionned in the terms of reference, some of them being obvious accident problems, others bearing on different preoccupations such as developping the traffic infrastructure or reorganising the transport administration. It appeared, after discussion with our Estonian partners, that the scenarios were going to be presented to Parliament in order to select a course of action based on a minimum consensus of the society.

To the team of experts, it seemed illogical to base alternate scenarios on heterogenous issues: how could one possibly choose, for example, between a course of action primarily aimed at improving pedestrian safety, and another based on a maximum of engineering measures involving the Estonian Road Administration (ERA) ? If the main criteria of choice were to be the cost benefit performances of each action scenario and the main issues addressed, a lot of care was obviously needed in re-defining relevant issues. It was also assumed that if the choice of policies was ultimately to be made by members of Parliament, those were not road safety specialists and therefore would not have sufficient bases to assess the validity of the methods used to design the proposals and analyse their content in details; as elected representatives, they would also be inclined to judge mainly from a social viewpoint, which meant that issues must reflect clear options for the development of the Estonian society and way of life.

The working team finally agreed to base the options proposed for the final choice on objective problems emerging from accident analysis. All options would have a common core including the organisational and safety measures that were considered essential and inavoidable in view of the present accident situation and safety management system; each option would in addition treat more in-depth one prominent problem. After a first level of safety diagnosis aimed at identifiying the main target-problems, the choice was the following:

1. Emphasis on accident severity and on injuries to vehicle occupants: Accident severity was found very high in Estonia in comparison with other European countries 20 fatalities per 100 injury accidents in 1993-96), and this did not seem particularly related to a deficit of recording of non-fatal accidents; also, vehicle occupants were a most important safety target as they accounted for 40 % of urban road fatalities and over three quarters of the fatalities on rural roads.

2. Emphasis on pedestrian safety: In 1993-95, pedestrians were involved in a third of all road accidents in Estonia and nearly half the urban accidents and accounted for a fifth of the fatalities on rural roads and over 40 % in urban areas. These figures were already shown to have increased in 1996 and the rapid growth of urban traffic promised a worsening of the situation.

3. Emphasis on safety in urban areas: Nearly two-thirds of all accidents in Estonia occurred in urban areas, making 40 % of fatalities; as for pedestrian safety, the fast growth of urban traffic, mostly at the expense of public transport, promised further deterioration of the situation. Little had been done so far to improve safety in urban areas as most town or city authorities had other priorities, and a scenario thus oriented implied a new form of relationships between local authorities and the central administration responsible for road safety.

4. Emphasis on rural accidents on the national road network: Accidents on national roads made 30 % of all fatalities in the country and were mostly concentrated on the three main routes from Tallinn to Tartu, Pärnu and Narva. As there were plans to develop these major infrastructure links to cope with the expected traffic increase, there was an opportunity to seize for accident prevention, as a large reduction of fatalities should be obtained by concentrating resources on a relatively small part of the network.

5. Emphasis on traffic in difficult conditions: Accident risk was found particularly high at night as nearly 40 % of accidents occurred during the dark hours, making nearly half the fatalities. Also a significant proportion of accidents occurred on muddy, icy or snowy roads and there were indications that risk was higher for urban traffic in the winter months. Estonia being a Nordic country, difficult travel conditions are the rule for good part of the year.

The issues addressed in the five options were not independant: for example, the large proportion of pedestrian accidents contributed to the high accident severity; safety policies in urban areas and on the national road network both included some measures to protect pedestrians; reducing accidents in difficult traffic conditions involved action both in urban areas and on rural roads; etc. The global mix of measures to be considered in each of them was, however, widely different. It was also felt that the issues could have a clear meaning for decision-makers and showed the societal choices involved: scenarios with emphasis on vehicle occupants would illustrate a clear priority given to the development of private vehicle traffic, with only minimum attention to traffic participants using public transport, walking or cycling; scenarios with emphasis on pedestrian safety and on urban areas would, on the contrary, indicate a priority to the less favoured road users

(economically speaking) and the quality of everyday life, while initiating a completely new way of managing urban transport systems, on the basis of a joint involvement of national and local authorities; scenarios with emphasis on the primary rural road network would contribute to the general effort of modernizing the country while giving priority to the unheeded development of private vehicle traffic and concentrating the road safety effort in the hands of the national administration.

In order to further facilitate decision-making, it was found useful to describe each of the scenarios thus designed in terms of partnership (types of decision-makers and sponsors involved) and in terms of the main sectors of action that would intervene (management organisation, urban planning, road engineering, law and enforcement, information and education, vehicle technical checks, rescue services, professional training).

Problems with the safety diagnosis

According to the terms of reference, the team of experts was expected to design scenarios for safety action on the bases of whatever data was available in the country at the time of the study and of their own experience in other countries. No funding would be available for field investigations or for complementary data collection. In other words, as little time and effort as possible was to be spent on identifying problems. This proved quite unsatisfactory for experts who worked according to the principles that: (i) in order to be efficient in reducing accidents or injuries, the road safety measures considered as possible parts of an action programme need to address real accident problems, identified through objective methods; and (ii) accidents are the effect of some malfunctions in the road and traffic system, so that a thorough analysis of past accident processes and factors is needed to indicate what such malfunctions could be and the possible way(s) to correct them. Road safety work thus requires a rather complex diagnosis, based on both statistical data and detailed accident descriptions, and additional investigations, particularly of potentially dangerous items of road user behaviour, may be found necessary (Muhlrad, 1989, Ferrandez & Girard, 1995, Lassarre & Muhlrad, 1996).

The Estonian Road Administration managed a comprehensive and reliable enough national accident file, based on accident forms provided by the Police. However, the data collection procedure had not changed since the old times when the Police was responsible for road safety management at the national level and mostly included in their policies enforcement and, to a lesser degree, education. As a consequence, items of data recorded for each accident were defined with emphasis on behavioural « errors » and provided little information on how the collision actually happened. The « errors », often considered as traffic offenses even when they were not defined as violations of official rules, reflected a number of current prejudices, particularly with regards to pedestrians, and could not be used as objective data. As the police stored the detailed accidents reports, samples of them could have been analysed to provide better understanding of how accidents happened, but the funding necessary for this tedious part of the diagnosis could not be obtained from the PHARE programme before the time when scenarios had to be finalised.

On the basis of statistical data and their past knowledge of accident mechanisms, the working team could only make assumptions as to the probable processes and factors generating the main accident problems; it was impossible to check that these assumptions were right in the Estonian context, and, even more, to assess the relative importance of the various factors identified in order to put them in priority order. As a consequence, none of the assumed factors could be eliminated *a priori*, and a large number of road safety measures had to be considered: the diagnosis provided no rational basis to choose between them while still ensuring effectiveness of the action programme. The scenarios designed were thus extensive and (obviously) costly, and some waste of resources could be expected from the fact that: (i) it was impossible to assess the actual capacity of individual measures to reduce accidents or injuries, and (ii) some measures were bound to be redundant as addressing inter-related accident factors. Clearly, more time and resources devoted to a an in-depth diagnosis would have produced more selective scenarios, easier to fund and implement, and to monitor.

As it was, it could be expected that none of the scenarios proposed would be fully implemented because of the limited resources available; most probably, decision-makers would select particular measures in each scenario according to the opportunities for funding and facilities for implementation (including expected acceptability for the public), which would introduce a risk of inconsistencies in the programme. This was, to some extent, taken care of by putting forward a common core of measures deemed essential and included in all scenarios: it was hoped that these measures would be considered as a vital minimum.

Another problem arose in the diagnosis phase. Although the ERA data base could provide accidents statistics for quite a long period, it was decided to analyse data only for the years 1993-95, following the changes that occurred in the Estonian political and economic system: quite clearly the new traffic situation was not comparable to the old one, due to a sharp increase of car ownership and private vehicle travel, and probably as well to a significant change in road users' attitudes with regards to mobility, safety, regulations, etc. Over the period 1992-95, a slow increase of the numbers of accidents and injuries was observed (with seasonal variations) while fatalities remained stable. However, at the beginning of 1997, while the scenarios were being designed, the statistics for 1996 became available and showed such a sharp *decrease* of accidents (- 20 %) and, even more, of fatalities (- 36 %), that the question arose of the validity of data and of the diagnosis. Investigations showed that, although a new accident recording procedure was being planned, no changes had yet taken place and it seemed impossible to relate the unexpected variations of accident figures to any recent flaw in the data collection. Attempts were made at explaining at the sudden safety improvement, taking into consideration particularly: (i) bad winter conditions that probably produced a reduction in traffic, (ii) increased seat-belt wearing which was observed following a safety campaign launched by ERA, (iii) intensified enforcement of speed limits and of the drinking-and-driving law, and (iv) improved quality of vehicles related to a large number of newly bought ones as well as to mandatory technical checks. Together, these factors could barely explain half the reduction in fatalities.

As Estonia is a small country (about 1.5 million inhabitants), numbers of accidents and fatalities are statistically small (1644 injury accidents and 332 fatalities in 1995), so that variations can be partly explained by a random effect. However, this effect was not so potent in the previous years and it can be assumed that other changes may have played a part, most probably behavioural and attitudinal ones. Some pycho-sociological research would be necessary to check this, but none could be undertaken in the course of the study. It remains that researchers or experts are seldom faced with a situation like the Estonian one and the experience of the working team was really inadequate to assess the new trend properly. It could be said that applying knowledge and methodologies to countries where safety research has so far been limited is acceptable as long as the road safety situation varies according to a known model, but as soon as freak variations occur, some analysis of the economic, social and psychological context becomes sorely needed.

The difficulties of assessing road safety trends had serious consequences, particularly when performing an economic evaluation of the various scenarios proposed. One redeeming fact was that, when taking into account the statistics for 1996 in addition to the four-year period already considered, the hierarchy of the main accident problems did not change: the five issues emphasized in the five groups of scenarios did not have to be re-discussed.

In addition to the safety diagnosis, an investigation of the structures and means available for safety management was also performed, aimed at identifying the roles played by different partners (ERA, the Police, the Ministry of Transport, etc.), the working procedures related to particular areas of action (road user information, technical checks of vehicles, police enforcement, driver licensing, etc.), and the problems expected to arise when implementing parts of the future safety policies (for example, urban safety programmes). Again, this was not easy as some changes kept occurring during the study, particularly in the legal environment.

Problems with programme design

Following the diagnosis, alternate scenarios were built in a logical way, using two parallel approaches: identifying *corrective* measures, aimed at preventing further occurrence of types of accidents which had been observed in the past, and *structural* measures, aimed at getting the traffic and the road safety management systems to work more smoothly. In the first case, effectiveness of measures can be directly related to the number of expected accidents or injuries avoided. In the second, the measures do not address any specific accident target, but as they contribute to optimizing the traffic management system, it is expected that, over a period of time, they should both decrease the amount of malfunctions that could generate unsafety and reduce the amount of resources wasted.

The methods used to design the road safety scenarios for Estonia can be summarized as follows:

1. The corrective approach: For each main issue (or safety problem) identified, possible accident factors or processes were listed, and the safety measures that could be efficient to eliminate or neutralize them were examined on the basis of current knowledge. The measures retained were combined in scenarios according to: (i) the particular issue addressed, (ii) the necessary associations of different kinds of measures (for example, new regulations and corresponding information campaigns), (iii) the schedule of implementation of the measure and the time needed for any effects to be observed.

2. The structural approach: Measures were considered, first to adapt the existing decision-making structure in Estonia so that appropriate channels could be found to implement all the components of the proposed road safety programme, and second, to improve the existing procedures for different tasks that were already being carried out but needed optimization (data recording, treatment and dissemination, periodical vehicle checks, enforcement, road user information, etc.). In addition, training requirements were assessed and some road safety training seminars or networks were introduced in the package. As the structural measures did not depend on specific safety issues, most of them were included in the common core for all scenarios, in the short or in the medium term.

The cost of the various measures was estimated and the partners expected to get involved in their implementation identified. The total cost and complete pattern of partnership could then be shown for each scenario.This part of the study went on smoothly, in spite of the fact, as explained earlier, that too many measures had to be included in the scenarios, due to the limited scope of the diagnosis. Also, some structural measures, such as the mandatory periodical checks of vehicles, may not have been urgent or may have been replaced by simpler measures if the Estonian administration had not already organised an activity of this kind: it seemed to be less costly and more acceptable for the decision-makers to improve the existing organisation than to terminate it for the time being. Altogether, the scenarios proposed were far from optimal, but they were at least logically built and addressing real serious issues.

Unfortunately, by the time the work was nearly completed, the decision-makers requested that the scenarios be designed in order to obtain a specific reduction of road fatalities in the year 2000. In other words, the demand for alternate scenarios was replaced by a demand for a targeted safety programme. The working team got very embarrassed as the way the quantitative target was defined was unclear, but what was clear was that none of the scenarios could meet it. It was stated that an approach to designing a targeted safety programme was different from the one followed: first, the target would have to be set rationnally in view of the current accident trends and of the curb of future expected accidents if no preventive action was undertaken; then, measures would have to be chosen according both to the frequency of the accident factors they addressed and to their estimated potential of reducing fatalities, in order to optimize the overall effect (in the process, it is likely that some of the structural measures would have to be eliminated). Obviously, this could not be realistically done with the data available, as can be seen from the comments on the diagnosis. More generally, it seems difficult in the present state of our knowledge to quantify a target for action in countries such as Estonia where traffic patterns

have not yet stabilized and there are no valid models to forecast accident or fatality trends over a number of years.

Problems with the economic assessment of the scenarios

The terms of reference of the Estonian road safety study stated that a cost-benefit assessment of each of the scenarios proposed had to be performed. The cost of measures was roughly estimated, based on international experience (for safety campaigns, for example) as well as on local cost values (for infrastructure measures, organisational changes, training workshops or networks, etc.). Some costs were difficult to establish when mostly based on the use of manpower (as for police enforcement), as the number of man x hours spent on safety activities was not individualized in administrative budgets. However, it is the assessment of benefits that raised the most serious questions:

1. A cost of human life as well as of injuries and material damage from accidents had to be established and accepted by our Estonian partners. A previous estimate had already been performed in the country, based on the « gross output » approach; however, it took into account only economic calculations (loss of production) and objective costs and did not include the costs of grief, pain and suffering which are usually part of the estimate in European countries. In order to get a figure for the cost of human life in Estonia that could be compared to those used elsewhere, the figure available had to be augmented. The final figure put the cost of human life in Estonia in the bottom end of the range of values used in the European Union.

2. There are internationally accepted values of efficiency for the most usual safety measures (or packages of measures), such as speed limits, mandatory seat belt wearing, some infrastructure improvements, etc. In order to apply them to the Estonian situation, some assumptions had to be made as to the actual effects on average speeds of additional enforcement of speed limits, the increase of the rate of seat-belt wearing obtained through additional information campaigns etc. But the main problem was that a reference situation had to be defined (the « do-nothing » scenario) against which expected reductions of accidents or fatalities would be computed. In countries with a steady growth of traffic over a long period of time, some models (for example as developed at SWOV) have been used to try and forecast a trend of accidents; it is impossible to fit such kind of model to a country where only a four or five year time-series of accidents can be used. As no better approach could be found, the economist of the team proposed to compare the Estonian situation to that of Western European countries at a time when traffic was growing very fast and road safety action was only beginning (in the 70s). However, the reverse in trends of accidents and fatalities observed between 1995 and 1996 later showed that there might be elements influencing the traffic safety situation that had not been experienced earlier in Western European countries.

3. In order to estimate the global benefits to be expected from one given scenario, some procedure had to be found to aggregate the individual benefits expected from each measure (or package of associated measures) that was part of it. Some obvious points had

to be considered: (i) the measures aimed at reducing exposure have a basic effect on the targets concerned; (ii) the measures aimed at reducing risk adress targets already reduced by decreased exposure; and (iii) the measures aimed at reducing the severity of the injuries sustained in collisions adress targets reduced by both decreased exposure and decreased risk. A comprehensive model taking care of relationships between road safety measures applied simultaneously had, to our knowledge, not yet been designed. Such a model would, in any case, have relied on a large number of variables whose values would have been difficult to estimate without additional field investigations. It was therefore decided to simply reduce the individual expected efficiency of each measure by a standard percentage (25 %) before aggregating effects.

4. Benefits of safety measures are usually estimated on the basis of first-year-return. When designing road safety programmes in the short, the medium and the long terms, such limitation does not quite make sense. Some safety measures (information campaigns, etc.) do have decreasing effects in time, but others (infrastructure improvements, etc.) have continuing effects that may even increase with traffic growth and that will influence accident or fatality trends in the long term. Expected reductions in fatalities of each scenario therefore had to be computed over at least the period concerned by the safety programme (1997-2010).

Altogether, the economic assessment of each of the scenarios proposed was conducted methodically, but was based on so many assumptions and rough estimates that the cost-efficiency values obtained could only be considered as indicative and had to be used with the utmost care. One should wonder whether the decision-makers requesting such figures actually use them when making final choices and whether the result is worth all the work involved in obtaining them. More effort put into the diagnosis might have proved more fruitful....

Conclusions

Working on a study such as the Estonian Road Safety Programme was an interesting experience, as it showed work areas for which sound methodological tools are still lacking and it demonstrated the limitations of past road safety experience acquired in countries of the European Union when applied to fast changing social and traffic conditions. On these bases, new directions of research could be formulated; in particular, better methods for assessing *a priori* the overall effects of a safety programme should be found, and field surveys and investigations would be necessary to understand the processes influencing accidents in countries such as Estonia.

However, such type of work leaves the experts somehow unsatisfied. One problem is that the terms of reference of road safety studies are obviously not systematically performed by road safety specialists and the amount of investigations required is grossly underestimated. To use an obvious comparison, one could say that the same situation would occur if asking a physician to perform a diagnosis on a patient while refusing him all means to order blood tests, x-rays or other such examinations, even when he needs

them; the final treatment may not be the most efficient in the circumstances (even if the doctor is experienced !). Another problem is that the demand expressed is unstructured and mixes up elements belonging to different categories: safety issues (accident problems) are compared with administrative or organisational issues; targeted safety programmes are not differentiated from programmes aimed at treating specific « issues »; structural measures are considered on a level with corrective measures, although aim, time-schedule, implementation and evaluation methods are quite different. Finally, an economic assessment of the scenarios designed for safety action is requested while it is clear that so many assumptions and estimates have to be made that it is doubtful whether the amount of time spent on it is worth the results.

Such experience shows that the role and status of researchers or other road safety professionals participating in operational studies is unclear and needs to be better defined. A guide of good practice, providing guaranties of minimum methodological bases, should be elaborated and promoted in order to get it accepted by the various international donors or money-lenders.

References

Ferrandez F. & Girard Y., 1995. *L'accident: méthodes d'analyse et applications.* In: Projet de Recherche sur les Politiques Intégrées de Sécurité Routière: Eléments de base pour un cours de sécurité routière. Tome 1. Rapport de Convvention DSCR/Inrets n° 92-41029, Inrets-Dera, Arcueil, France.

Lassarre S & Muhlrad N., 1996: *The accident as a multifactorial phenomenon: systems approach to road safety.* In: Introduction to road traffic safety: a multidisciplinary approach (Mohan D. & Muhlrad N. ed.). Centre for Biomedical Engineering, Indian Institute of Technology Delhi, New Delhi, India.

Lassarre S & Muhlrad N., 1996: *The safety diagnosis.* In: Introduction to road traffic safety: a multidisciplinary approach (Mohan D. & Muhlrad N. ed.). Centre for Biomedical Engineering, Indian Institute of Technology Delhi, New Delhi, India.

Muhlrad N. (1989): *Integrated safety policies: planning, management and monitoring.* Second African Road Safety Congress, Addis Ababa, October 1989. Compendium of papers, TÖI, Oslo, 1991.

Muhlrad N. (1994): *Improving decision-making processes in road safety.* Invited paper. Proceedings of the Third International Conference on Safety and the Environment in the 21st Century, Tel Aviv, November 1994. Ministry of Transport, Tel Aviv & Technion, Haïfa.

Viatek-BCEOM, 1997. *The Phare Estonian Road Safety Programme.* Draft Final Report. Viatek Group, Espoo, Finland & BCEOM, Guyancourt, France.

THE ROAD TRAFFIC ACCIDENT SITUATION IN GHANA

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ABSTRACT

Despite the immense contribution of road transportation to the rapid development of most developing countries, it has now become a socio-economic problem. The rapid rise in the number of automobiles has contributed to increased traffic accident deaths and injuries every year. In Ghana, co-ordinated efforts to reduce traffic accidents have been geared towards educational campaigns, traffic law enforcement and low-cost engineering measures but indications are that road accident fatalities continue to rise. This report analyses the status of the traffic injury accidents in Ghana in 1991 following the inception of the World Bank sponsored Ghana Road Safety Programme in 1988.

Specific conclusions of the analysis include the following:

- The average fatalities per 10,000 vehicles is about 2.4 times or 16 times higher than what pertains in Botswana in Africa or Great Britain in Europe respectively.

- Pedestrian fatalities alone account for nearly 48% of all the traffic accident fatalities in Ghana.

- There are pronounced regional differences in accident characteristics. For example, despite the general rise of 3.6% in traffic accident fatalities at national level, significant road safety improvements have been experienced in about five (5) of the ten (10) regions in Ghana.

- About 70% of all road accident fatalities occur in rural areas, compared to 30% in urban areas.

Overall, it can be stated that multifaceted accident countermeasures must be applied to help bring about road safety improvement in Ghana.

1.0 INTRODUCTION

Road transportation, despite its immense contribution to rapid development of societies has now become a socio-economic problem. The consequence of road traffic accidents continues to be a drain on the scarce financial resources of the developing as well as developed nations. However, the road safety situation in developing countries unlike that in Western Europe and North America, appears to be worsening (Jacobs and Wendy, 1978; Jacobs and Fouracre, 1977).

In 1988, as part of the World Bank sponsored Transport Rehabilitation Programme (TRP), the government of Ghana initiated the Ghana Road Safety Project (GRSP) to address the worsening road safety situation. Under the programme, an Accident Data Collection and Analysis Unit was set up at the Building and Road Research Institute (BRRI) of the Council for Scientific and Industrial Research (CSIR), Ghana, to collect and analyse road accident data so that the nature of the problem could be identified for subsequent application of appropriate accident countermeasures.

In recent years, road safety awareness has been created in Ghana through numerous campaigns directed to the public through radio, television, newspapers, workshops and seminars. Nonetheless, it is unfortunate to note that, sometimes such campaigns are carried out with questionable significance in relation to the real road safety problems that the road user needs to be aware of. This paper therefore highlights the road accident situation in Ghana with the view to elucidating the nature and characteristics of the road traffic accidents for a more effective and systematic approach to the prevention of road accidents.

2.0 DATA COLLECTION AND ANALYSIS

In Ghana, the Police have a traditional duty to visit every accident site and record the accident details. Throughout August 1992, the various designated Police Stations were visited by the BRRI staff to transfer the accident details onto an Accident Data Form designed by Ross Silcock Partnership, United Kingdom (Ross Silcock Partnership, 1990). The accident data collected was then coded and stored in a micro-computer for subsequent analysis.

For this report, only road accidents involving personal injury were analysed with the help of MAAP5 accident analysis package developed by the Transport Research Laboratory (TRL), United Kingdom, on ordinary micro-computer systems.

3.0 RESULT

3.1 Trends in Road Traffic Accidents in Ghana

The general road traffic injury accident characteristics in Ghana for the period 1988 to 1991 are shown in Table 1. There is an upward trend in the number of recorded accidents in Ghana, rising sharply from 4,355 in 1988 to 5,165 in 1990 and then dropping slightly to 4,949 in 1991 thereby registering a growth rate of between 4.3% and 6.5%per annum.

The number of road accident fatalities as well as injuries recorded during the period also appeared to rise consistently, signifying the nature and magnitude of the road safety problem in Ghana. However, the fatality rate in terms of fatalities per 10,000 vehicles which is a measure of exposure to risk suggests a downward trend from a level of 118 in 1988 to 77 in 1991, giving an average of about 88 fatalities per 10,000 vehicles for the four-year period. This average figure is however very high when compared with other

developing and developed countries. For example, the figure is about 2.4 times or 16 times higher than what pertains in Botswana or Great Britain respectively (Jacobs, G.D., 1986).

TABLE 1: SUMMARY OF ROAD INJURY ACCIDENT CHARACTERISTICS IN GHANA: 1988 – 1991

ACCIDENT STATISTICS	YEAR			
	1988	1989	1990	1991
No. of Accidents	4355	4776	5165	4949
Fatalities	916	947	918	981
Injuries	9082	9867	10033	9240
No. of Vehicles Involved	5376	6004	6621	8051
*Population ($x10^6$)	13.757	14.134	14.522	14.920
** Licensed Vehicles	97544	115586	123892	126644
Fatalities per 10,000 Inhabitants	0.66	0.67	0.63	0.66
Fatalities per 10,000 Vehicles	118	82	74	77

Source: *Ghana in figures 1992 by Statistical Services, Accra, Ghana
**Ministry of Transport and Communication's Bulletin, January-December 1992, and projected by 20% to cover Government vehicles etc.

3.2 Regional Accident Characteristics

The road traffic accidents and casualty distribution in 1991 for the ten(10) regions of Ghana have been shown in Table 2. The 1991 road accident data when compared with the 1989 data showed an increase of about 3.6% for the whole country. The picture was however not the same for all the regions. For example, there were significant road accident reductions during the two-year period for Brong-Ahafo, Northern, Upper East, Upper West, Volta and Western Regions. The road accident trend was however upward for Ashanti (+6.4%), Eastern (+9.5%), Central (+11.4%) and Greater Accra (+19.5%) regions during the same period.

Considering the number of persons killed through motor accidents in Ghana in 1991 alone indicates that, the worst regions were Greater Accra, Ashanti and Eastern. However, road safety deterioration, viewed over the two-year period 1989-91, was rather horrendous in Volta Region (+61.4%), followed by Ashanti Region (+45.2%), Central Region (+38.0%) and then Greater-Accra Region (+6.8%). Nonetheless, there were road safety improvements in terms of decreases in fatalities in five of the regions during the two-year period namely, Upper West (-48.2%), Western (-44.4%), Upper East (-42.5%), Northern (-12.8%) and Brong-Ahafo (-10.2%). It is obvious from Table 2 that there are regional differences in the accident situation in Ghana.

Table 3 further reinforces the fact that there are regional differences in accident characteristics in Ghana. Whereas the most dominant road user groups at risk in Ghana in

general were pedestrians, followed by bus occupants and then car occupants, the situation was however different in the various regions. For example, the road user groups most at risk in the Northern and Upper West regions were Heavy Goods Vehicles occupants and bicycle/motorcycle users respectively as against pedestrians in the Greater Accra region and bus occupants in the Central region. Road safety improvement efforts should therefore be reflective of such regional differences in accident characteristics so as to bring about the desired reductions in accidents as well as to ensure cost-effective implementation of countermeasures.

TABLE 2: ROAD ACCIDENTS AND FATALITIES BY REGION – 1991

REGION	INJURY ACCIDENT	COMPARED WITH 1989 % Change	PERSONS KILLED	COMPARED WITH 1989 % Change
1. Ashanti	713	+6.4	183	+45.2
2. Brong-Ahafo	367	-15.2	96	-10.2
3. Central	390	+11.4	98	+38.0
4. Eastern	856	+9.5	183	+ 0.0
5. Greater Accra	1591	+19.3	187	+6.8
6. Northern	113	-5.0	41	-12.8
7. Upper East	110	-6.0	23	-42.5
8. Upper West	44	-42.1	13	-48.0
9. Volta	275	-20.4	92	+61.4
10. Western	490	-14.5	65	-44.4
All Regions	**4949**	**+3.6**	**981**	**+3.6**

TABLE 3: THE THREE (3) MOST DOMINANT ROAD-USER GROUPS AT RISK IN THE VARIOUS REGIONS OF GHANA – 1991

REGION	ROAD USER GROUP AT RISK		
	1st Order	2nd Order	3rd Order
1. Ashanti	Pedestrian (32.2%)	Bus Occupants (27.5%)	Car Occupants (18.8%)
2. Brong Ahafo	Car (22.0%)	Bus (19.6%)	HGV (17.2%)
3. Central	Bus (33.4%)	Pedestrian (20.8%)	Car (19.2%)
4. Eastern	Bus (25.4%)	Car (21.9%)	Pedestrian (20.9%)
5. Greater Accra	Pedestrian (38.5%)	Car (25.5%)	Bus (16.3%)
6. Northern	HGV (48.0%)	Car (14.0%)	Bicycle/Motorcycle (9.7%)
7. Upper East	Bicycle/Motorcycle (26.7%)	Pick-up (21.2%)	HGV (12.9%)
8. Upper West	Bicycle/Motorcycle (24.6%)	HGV (20.0%)	Pick-up (20.0%)
9. Volta	Bus (31.0%)	Pedestrian (18.0%)	Pick-up (17.5%)
10. Western	Pedestrian (26.0%)	Car (24.5%)	Bus (20.1%)
WHOLE COUNTRY	**Pedestrian (25.7%)**	**Bus (22.7%)**	**Car (20.8%)**

HGV = **Heavy Goods Vehicle**

3.3 Road Casualties in Ghana

3.3.1 Road Casualties by Class of Road User

Compared with other road user categories, pedestrians alone accounted for about 48% of all fatalities and about 26% of all road accident casualties in Ghana. Based on the percentage share of fatalities for the different road user groups in Ghana, the pedestrian deaths in motor traffic accidents are about 4.9 times that of the car occupants and 3.6 times that of the bus occupants. This reveals that the pedestrian is generally at risk in traffic in Ghana. The proportions of bicycle and motorcycle casualties are low compared with most European countries (Lamm, R. and Choueiri, E. M., 1991).

TABLE 4: DISTRIBUTION OF ROAD ACCIDENT VICTIMS BY CLASS OF ROAD USER AND FATALITY INDEX

ROAD USER CLASS	PERSONS KILLED		PERSONS INJURED		TOTAL		FATALITY INDEX
	No.	%	No.	%	No.	%	%
Pedestrian	458	47.7	2137	23.6	2595	25.9	17.6
Bus occupant	127	13.2	2143	23.6	2270	22.6	5.6
Car occupant	93	9.7	2005	22.1	2093	20.9	4.4
HGV	106	11.0	799	8.8	905	9.0	11.7
Mummy truck	70	7.3	700	7.7	770	7.7	9.1
Pick-Up	40	4.2	709	7.8	749	7.5	5.3
Bicycle	33	3.4	272	3.0	305	3.0	10.8
Motorcycle	16	1.7	236	2.6	252	2.5	6.3
Tractor	16	1.7	53	0.6	69	0.7	23.2
Others	1	0.1	15	0.2	16	0.2	6.3
Total	**960**	**100.0**	**9069**	**100.0**	**10029**	**100.0**	9.6

HGV = Heavy Goods Vehicle

Fatality index, which is a ratio of fatalities to the total number of casualties resulting from accidents, has also been adopted as a measure of risk for the various road user categories. Based on the fatality index it can be seen from Table 4 that the **pedestrian** is at risk as well as users of **tractor, Heavy Goods Vehicle** and **bicycle** as modes of transport. Indeed, the pedestrian and pedal cyclists are highly vulnerable in traffic in Ghana.

3.3.2 The Age Distribution of Casualties

The age groups used in the report (see Table 5), are indicative of the different stages in life: pre-school, 0-5; primary school, 6 - 10; secondary school, 11-15; university students and youth, 16 - 25; bulk of the workforce, 26-60; and senior citizens, over 60 years. Children below the age of 16 years constituted 14% of all road casualties and 29% of all those killed in road accidents in Ghana. Other recent studies (Afukaar, F.K., 1996; Mock, *et al.*, 1996) indicated that most of the children involved in road accidents were pedestrians knocked down by vehicles while crossing the road.

TABLE 5: ACCIDENT SEVERITY BY AGE

AGE	PERSONS KILLED		PERSON INJURED		ALL CASUALTIES	
	No	%	No.	%	No.	%
0-5	68	9.6	180	2.5	248	3.1
6-10	93	13.2	413	5.7	506	6.3
11-15	47	6.6	333	4.6	380	4.8
16-25	113	16.0	1756	24.1	1869	23.5
26-60	345	48.8	4387	60.2	4732	59.3
Over 60	41	5.8	209	2.9	250	3.0
Total	**707**	**100.0**	**7278**	**100.0**	**7985**	**100.0**

It can be seen that over 18% of all child casualties were fatal whilst the equivalent value for adults over 25 years was about 8%. Children in traffic are therefore generally at greater risk of being killed in an accident than adults. About sixty per cent of all casualties belonged to the working class. These data prove the seriousness of the economic loss to the community, and the urgency of remedial measures to be taken to curb the frequent occurrence of accidents.

3.3.3 Casualty distribution by number of vehicles involved in crashes

Table 6 shows that about 55% of all injury accidents occurred as single vehicle crashes, resulting in about 69% of all casualties and 75% of all fatalities. This was followed by accidents involving 2-vehicles only (43.2%, N=3475), resulting in about 29% casualties and 22% fatalities.

It can also be seen that 10.6% of all single vehicle casualties are fatal, the corresponding value for 2-vehicle crashes is 7.3%.

TABLE 6: CASUALTY DISTRIBUTION BY NUMBER OF VEHICLES INVOLVED IN CRASHES

NO. OF VEHICLE	ACCIDENTS	VEHICLES INVOLVED	CASUALTIES			TOTAL	%
			Killed	Serious	Slight		
1	4326	4326	742	2546	3719	7007	68.6
2	3475	6950	213	1016	1687	2916	28.6
3	28	642	23	89	146	258	2.5
4 or More	28	116	4	7	21	32	0.3
TOTAL	**8042**	**12034**	**982**	**3658**	**5573**	**10213**	**100.0**

3.3.4 Casualties in Urban and Rural Areas

About ten per cent of all road accident casualties in Ghana were fatal and 36 per cent were serious (see Table 7). About 40 per cent of all road casualties occurred in the urban environment whilst the remaining 60 per cent occurred on roads in rural areas.

From Table 7, it can be inferred that about 70.2% of all fatalities occurred on roads in rural areas of Ghana, and just about 29.8% on urban roads. Furthermore, it can be seen that about 8 per cent of all casualties in urban areas were fatal whilst the equivalent value in rural areas was over 11 per cent.

TABLE 7: INJURY SEVERITY IN URBAN AND RURAL AREAS

LOCALITY	FATAL		SERIOUS		SLIGHT		TOTAL	
	No.	%	No.	%	No.	%	No.	%
Urban	289	29.8	1348	37.1	2394	43.2	4031	39.7
Rural	682	70.2	2285	62.9	3150	56.8	6117	60.3
TOTAL	**971**	**100**	**3633**	**100**	**5544**	**100**	**10148**	**100**

4.0 CONCLUSIONS AND DISCUSSION

The analysis has shown that the road accident situation in Ghana requires immediate attention. The number of road accidents continues to rise for the whole country and an average fatality rate of 88 fatalities per 10,000 vehicles is rather high compared with some countries in Africa and Western Europe. For example, the traffic fatality rate is about 2.4 times or 16 times higher than what pertains in Botswana in Africa or Great Britain in Europe respectively.

There are pronounced regional differences in accident characteristics in Ghana. Policy makers and road safety administrators must therefore be aware of the nature and characteristics of the accidents for each region in order to adopt the most appropriate remedial measures to bring about the desired reductions in accidents at national level as well as to ensure cost-effective implementation of countermeasures. Indeed targeted and

coordinated approach to the designing of accident reduction interventions and accident prevention strategies holds the key to road safety improvement in Ghana.

Pedestrian deaths represent the single largest category of motor traffic related deaths in Ghana. Pedestrian fatalities accounted for about 48% of all road traffic accident fatalities in Ghana. The percentage share of fatalities for pedestrians (48%) is 4.9 times that of the car occupants and 3.6 times that of the bus occupants. The pedestrian as a road user is highly vulnerable and generally at risk. The pedestrian must therefore be a key target group for the prevention of accidents in Ghana. Proven low cost preventive measures such as separation of pedestrian pathways from vehicle routes, greater use of pedestrian Zebra crossing and traffic signals, and improved urban roadway lighting must be applied (Ross, Baguley, Hills, *et al*, 1991; Forjuoh and Li, 1996).

About 70% of all road accident fatalities occurred on roads in rural areas, compared to about 30% of fatalities in urban areas. Generally, 10% of all road accident casualties in Ghana are fatal, which is high compared with countries in Western Europe. There is however evidence that fatalities could be reduced in developing countries by improving medical facilities. In particular, an improved ambulance service would do much to ensure that lives are saved (Jacobs and Wendy, 1978). An improved communication network will also help to ensure that lives are saved.

Single vehicle crashes, including those of pedestrians, represented on an average about 75% of all fatalities. Due to the type of accident involving single vehicles, the proportion of those killed is about 3.5 times higher than those involving 2-vehicle crashes.

Children below the age of 16 years constituted 29% of all those killed in road accidents in Ghana. Over 18% of all child casualties were fatal whilst the equivalent value, for adults over 25 years, was about 8%. Children in traffic, particularly child-pedestrians, are generally at greater risk of being killed in an accident than adults. The safety of child pedestrians should be paramount in the prevention of accidents. Road safety education and road safety clubs should be promoted in schools to improve children's understanding on safe road crossing practices, pedestrian conspicuity at night, judgement of vehicle approaching speeds, etc. Urban planning must be used as a tool for road safety in urban areas and road safety research should be accorded high priority in developing countries to address road safety needs.

Integrated and systematic approach to the implementation of road safety measures is a sine qua non in road safety improvement in Ghana.

REFERENCES

Afukaar, F.K., (1996): A study of Personal Injury Accident Characteristics: A way forward in Road Safety Management in Ghana, Unpublished.

Forjuoh, S.N.; and Li, G. (1996). A review of successful transport and home injury interventions to guide developing countries. Soc. Sci. Med. (In Press), 1996

Jacobs, G.D., (1986). Road Accident Fatality rates in Developing Countries – a reappraisal. In: PTRC. Summer Annual Meeting, University of Sussex, 14-17 July 1986. Proc. Of Seminar H. London: PTRC Education and Research Services, pp 107-119

Jacobs, G.D., (1976): A Study of Accident Rates on Rural Roads in Developing Countries. Department of the Environment. TRRL Report LR 732. Crowthorne, U.K.

Jacobs, G.D., and Fouracre, P.R. (1977): Further Research on Road Accidents in Developing Countries, Dept. of the Environment. Department of Trnsport, TRL Report SR 270, Crowthorne, U.K.

Jacobs, G.D., and Wendy A. Hards (1978): Further Research on Road Accident Rates in Developing Countries (Second report), Transport and Road Research Laboratory, Supplementary Report 434, Crowthorne, U.K.

Lamm, R, and Choueiri, E.M. (1991): Traffic Safety on Two Continents: A Ten-Year Analysis of Human and Vehicular Involvements. Proceedings of the Conference STRATEGIC HIGHWAY RESEARCH PROGRAM AND TRAFFIC SAFETY ON TWO CONTINENTS in Gothenburg, Sweden. Sept. 18-20, 1991, Part I. VT1 Rapport, pp 121-136

Ministry of Transport and Communication's Bulletin, January-December 1992.

Mock, C.; Nii-Amon-Kotey, D.; Forjuoh, S, and Rivara, R. (1996): Epidemiology of Transportation Related Injuries in a Sub-Saharan African City. 40th Annual Automobile Medicine, Oct. 7-9, 1996, pp 171-185

Ross, A.; Baguley, C.; Hills B.; Mc Donald, M.; Silcock D. (1991): Towards Safer Roads in Developing Countries: A guide for Planners and Engineers. Berkshire, England; Overseas Unit, Transport and Road Research Laboratory.

Ross Silcock Partnership (1990): Ghana Road Safety Project: Final Report, Newcastle Upon Tyne; Ross Silcock Partnership.

Statistical Service (1992). Ghana in Figures 1992. Accra, Ghana.

A study of pedestrian activity and accident risk: implications for road safety policy

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Abstract

On an average day in an average English town, about three quarters of its residents aged five years and over will walk somewhere. Not necessarily very far, perhaps only from a parking space to the shops or place of work. Not everyone has access to a car and many people rely on their feet for independent mobility. This is especially true for the under 18's and over 65's and of women of all ages compared with men. Short walks need to be considered alongside the longer walks, say from home to the shops, school or office as people are vulnerable to being injured by traffic even when only one road is crossed. Indeed, a pedestrian need not be crossing the road to be injured by a vehicle.

We know quite a lot about where in the road environment pedestrians are injured, how old they are and whether male or female. What we do not know much about is who walks where, with whom and how far. A major study has been undertaken in which the relationship was investigated between how far people walked, how many roads they crossed and the layout of the roads near where they lived and alongside which they walked. The main findings were:

- the average distance walked per head of resident population was just more than 800 metres and females of all ages walk about 8 per cent further per person than males.
- teenagers walk furthest of all, about 1.66 km per day per person
- over half the distance a person walked was within 500 metres of home and about three quarters was within 1 km of home
- four out of five times a child aged between 5 and 9 years crossed a road they were accompanied by an adult
- older children were accompanied by an adult two out of five times they crossed a main road and only one in three times they crossed a local road

These levels of activity and exposure to traffic in the road environment were related to the

casualty figures to give casualty rates and risk indices for different people crossing different types of road. When exposure is taken into account the main findings were:

- the casualty rate per 100 million roads crossed for children aged 5-15 is twice the average rate for people of all ages and about four times that of adults in the age range 25-49
- males are about one and a half times more at risk of injury than females for every kilometre walked alongside traffic or for every road crossed. The exception is young teenage girls who are more at risk in the road environment than males or females of any age

The findings of this study have implications for policy at both national and local level in regard to the provision of education and training for all road users, for enforcement, the design and layout of new roads in urban areas, and the improvement of existing roads both in terms of management of traffic and pedestrians and in terms of changes to the road environment itself.

1 Introduction

How to encourage more people to leave their car at home and walk short distances is a central theme of policies to reduce car dependency. Before such policies can be formulated we need to know much more about why people walk, who walks, how far and where, at what time of day, and which kinds of road they walk alongside and cross. We also need to know more about what discourages people from walking so that the social and physical environments may be changed to reduce barriers to walking.

As a result of the many large travel surveys that have been undertaken over the years we know quite a bit about journeys by car and the travel patterns and habits of car drivers. We know far less about pedestrian activity. The road network, its management and the management of the motorised traffic that uses it has, for the past several decades, taken precedence over routes and facilities for pedestrians. The quality of the road environment in which we walk is important and in recent years more account is being taken of the need for safe and pleasant pedestrian movement. More attention has been given to creating pedestrianised town centres and other traffic free environments where people may meet and shop. The road environment is changing too with the needs of pedestrians being reflected in the introduction of more equitable traffic management measures.

Not everyone has access to a car and many people rely on their feet for independent mobility. This is especially true for the under 18's and over 65's and of women of all ages compared with men. Many people choose to walk to keep fit or to enable them to meet and talk to others on their way. In order to find out more about walking patterns, residents of Northampton, a typical British town, were surveyed as part of a study undertaken by University College London which was

commissioned by the AA Foundation for Road Safety Research. In the first part of this paper a brief outline of the research methodology is given together with the main findings. The second part highlights the implications for policy at both national and local level for the development of strategies for walking. The policy areas covered include provision of education and training for all road users, traffic law enforcement, the design and layout of new roads in urban areas, and the improvement of existing roads both in terms of management of traffic and pedestrians and in terms of changes to the road environment itself.

2 Pedestrian activity and accident risk

2.1 Collection of walk information

Northampton was chosen in which to collect information about walking because it is a medium sized town which has a typical pattern of streets and housing types ranging from victorian terraces near the town centre through all ages of housing until the present day which are located on the eastern and western outskirts of the town. The age distribution of people living in Northampton is typical of a town of its size so is its ethnic mix and number of cars per household. About 264 000 persons aged five years and over lived in Northampton at the time of our study in 1992 to 1994, with females making up 51.5 per cent of the population.

A stratified sample of about 400 households was chosen and every resident aged five or over was asked to fill in a diary of their activity on foot over a 24 hour period determined by the study team. In this way walk information was collected from 1037 residents. The importance of this approach was that it sampled across the different types of housing which in turn include the various road layouts which people walk alongside and cross. The main weakness of using this sampling method was that it concentrated on households rather than on individuals who ultimately provide the basis for exposure data so some gender and age groups were not sampled in quite the same proportions as found in the population of Northampton.

Respondents to the surveys provided a wealth of information about their pedestrian activity but they could not be expected to recall all the characteristics of the road environment in which their walking took place; enough of their time had been taken up with asking then to describe the route they had taken for each walk and where they had crossed each road. Information about the road environment in which each walk took place was collected by a member of the study team who rewalked the routes described and noted the presence of features of the road and roadside using a classificatory system devised to deal with all the information about each walk.

2.2 Pedestrian activity in the road environment

On an average day the 164 000 residents of Northampton walk a total of 133 000 kilometres and

cross about 636 000 roads. This is the equivalent of about 825 metres for each man, woman and child aged five and over. About three quarters of the residents walk somewhere on an average day even if it is only from the house to a car parked nearby or the post box on the corner. If just the people who walked somewhere are considered then the average distance walked was about 1.15 kilometres and about 5.5 roads were crossed.

Males and females do not walk the same distance in a day as, on average, females walk about 8 per cent further than do males. In distance this translates to about 100 metres for each female who walks. The distance walked is not uniform across all age groups. The results of the study show that young women aged 16-19 and 25-34 years walk substantially greater distances than males of the same age, and further too than males or females of any age. Male children walk further than female children with 10-15 year old boys walking nearly twice as far as the girls. Within these patterns of distance it is interesting to note that about 60 per cent of all walking is done within 500 metres of home. Men do a greater proportion of their walking further from home than do the women but the extra 100 metres distance the women walk each day is on the roads close to where they live.

That most walking is on streets close to home is consistent with another finding that most walking is on residential roads. This may not be a profound finding at first sight but it does have relevance to wider issues of how people relate to the environment near to where they live and how educational material relating to the use of roads should be targeted.

One of the determining factors in the amount of walking is health and general mobility. Data from the 1985/86 National Travel Survey show that people with a physical or long-standing health problem that makes travelling difficult, make on average about half the number of journeys made by people without such problems (Oxley 1993). In our study people were asked how often they had gone out in the previous week and whether they had any health problems that affected their mobility. Eighty three of the people we interviewed reported a health difficulty. However, nearly two-thirds of these went out on foot on their survey day. We interviewed 24 people who were registered disabled and of these, half went out somewhere on foot.

Whether or not a car is available to the household may affect the amount of walking by household members. Nationally, about 87 per cent of 5 to 10 year olds who live in households where there is no car, walk to school. For households with one car, about two-thirds of the children walk to school but in families where there are two or more cars, only 36 per cent of these children walk (Department of Transport 1995). About three quarters of the people we sampled lived in households with access to a car, which is about the average for Northampton. We found that people living in households without a car walk further than those with a car; one kilometre compared with three-quarters of a kilometre. But whilst they walk further they tend to make fewer walks. people who live in households where the head was not in regular employment and there was no car are appreciably less likely to walk than any other group.

Accompaniment or escorting of children by an older child or adult is common, especially when the younger child needs to cross a busy road. In our study we found the 5-9 age group were

accompanied by an adult on 77 per cent of the times they crossed a road and a further 10 per cent were in the presence of older children.

We recorded the time the walks started and finished and found that in the seven hours 07.00 to 09.59 and 15.00 to 18.59 about half the total distance for the day was accounted for. On average about 8 per cent of all walking by residents is done in hours of darkness.

Hillman et al (1990) found that 98 per cent of junior school children and 76 per cent of senior schoolchildren are not allowed out alone after dark. This together with Hillman et al's finding that increasingly children are being accompanied by car on the school journey lead them to identify five adverse consequences:

increased resource costs
constraint of adult opportunities
contribution to increased traffic congestion
removal of a routine means for children to maintain physical fitness, and
limitation of opportunities for the development of independence.

The 16-19 year age group do nearly a quarter of their walking in the evening after 19.00 hours but the largest amount, nearly 600 metres a person, is started between 15.00 and 18.59. This together with the finding that they venture further away from home on foot and cross more main roads than any other age group indicates they are perhaps travelling to the town centre where there is not only a greater concentration of main roads but is where the activities are located that attract young people in the evening.

Perhaps not surprisingly, people aged over 65 year do two thirds of their walking between 10.00 and 14.59. These older pedestrians have a walking pattern more similar to that of children than to that of adults with about 85 per cent of the distance they walk being within one kilometre of home. The main difference being the number of main roads the older people cross. Children cross on average one main road every other day whilst the older pedestrian crosses about one a day. This is probably a reflection on where in the town the older people live and their lifestyle which includes visiting the shops which tend to be located on or near to main roads. Carthy et al (1995) report that shopping or looking around shops comprised the majority of outings for the older age group in their study, and represented two out of every three trips. A common destination was the city centre.

Car ownership and use is not distributed evenly across the age range of people in Northampton. From our data we could determine where the walk started from. About one third started from home, a third from another walk, a further quarter started from a car and in Northampton, only three per cent started from the bus. The 16-19 year olds and the older people were the greatest users of the bus with about 11 per cent of their walks starting from a bus journey.

The destination of walks also shows an interesting pattern across the age groups. The 16-19 year age group links fewer walks to a car than any other age group which again highlights their

independence and lack of personal transport other than their feet. By contrast, the 50-59 year age group link more of their walks to a car than any other age group. In general, about 30 per cent of the walks done by the people of Northampton are 50 metres or shorter but these represent only about one per cent of the total distance walked. Of these very short walks, about 44 per cent are to a car. Over two thirds of all walks are no longer than 350 metres and of these nearly a third are to a car whilst only three per cent were to a bus stop.

The differences in patterns and amounts of walking by people of different ages, gender and personal circumstances briefly covered in this paper highlights the complexity of the task facing those responsible for planning new and improving existing pedestrian environments.

2.3 Where in the road environment are people injured?

The location in the road environment together with the distribution over time of accidents involving injury to pedestrians are of importance to those involved with making the roads safer and more pleasant for all people as pedestrians.

In Britain about 95 per cent of all pedestrian casualties are injured on roads where there is a speed limit of 40 miles/h or less. There is comparatively little walking in rural areas and alongside the faster roads which explains the predominance of the problem in urban areas. Because pedestrians are vulnerable to injury when struck even at low speeds by vehicles, the proportion of all injuries sustained by pedestrians that are fatal or serious is higher in urban areas than for say, occupants of cars who are protected by the vehicle shell itself. The proportion of pedestrian injuries which were fatal or serious in Northampton for the period we studied was 37 per cent which is somewhat higher than the national average of 27 per cent.

Crossing main roads is difficult for pedestrians of all ages with half of all injuries occurring there. These roads are especially difficult for those over the age of 60 years as nearly two-thirds of injuries to this group of people are sustained whilst crossing these busy roads. This age group tended to be more severely injured than would be expected from national figures with 57 per cent being killed or seriously injured on Northampton's roads. Up to the age of 60 years more males are injured than females of the same age.

Children and young persons between the ages of 5 and 15 years comprise 39 per cent of all pedestrian casualties. None was killed in the five year period studied but 89 were seriously injured. Whilst older pedestrians tend to be injured whilst crossing or walking alongside main roads, children of school age are injured closer to home with 68 per cent of their injuries being sustained on the residential roads. In this age group boys are injured more frequently than girls in a ratio of approximately three to two.

The fact that most walking is done close to home has already been discussed and in relation to this it is of interest to look at where the casualty was injured in relation to home to see whether the injuries occur on the very familiar streets close to home or on those some distance away. The young children were injured close to home with 80 per cent being injured within 1 km and over half injured within 400 metres. Older children venture further afield and this is reflected

in their injury pattern with 40 per cent of the 10-15 year olds being injured within 400 metres of home and two-thirds within one kilometre. The wide ranging 16-19 year olds tend to be injured at places more distant from their homes with only 17 per cent of casualties being within 400 metres of home. The older pedestrians have an injury pattern more like that of children with 73 per cent of casualties being within 1 km of home. These patterns are not surprising given where the walking is done and serve to reinforce the need for safe access to shops, schools and amenities for all age groups whether they live on a quiet or a busy road.

2.4 Pedestrian accident risk

Much is known about casualty rates and levels of risk for drivers and passengers of vehicles as estimates of distance driven or passenger kilometres have been collected for some time, for example as part of the National Travel Survey (DOT 1993a). These casualty rates are expressed per 100 million kilometres. The casualty rates in common usage for pedestrians is expressed in terms of per 100 000 population as no current measures of exposure exist for walks of all lengths on different types of road by people of different ages.

We have estimated that the residents of Northampton walk 133 000 km on an average day and cross some 636 000 roads. All this activity results in about 0.43 pedestrian casualties a day. Expressing this as a casualty rate gives 411 casualties per 100 million kilometres walked or 66 casualties per 100 million roads crossed. Whilst in reality it takes the people of Northampton nearly three years to walk this far it does provide a casulty rate which is expressed in similar terms to those for drivers and passengers of vehicles. For 1992 data the casulty rate per 100 million vehicle kilometres for bicycles was estimated to be 526 and for car drivers to be 34 per 100 million vehicle kilometres (DOT 1993b).

Estimates of the amount of walking indicate that females walk a greater distance and cross more roads whilst the casualty information indicates that males are injured more frequently than females. When the amount of walking is considered along with the number of casualties we find that females have a casualty rate of 263 per 100 million kilometres walked, or 54 per 100 million roads crossed while the corresponding rates for males are higher at 386 and 82 respectively.

The casualty rates per 100 000 head of population indicate that boys aged 5 to 15 years are about one and a half times more at risk of being injured as pedestrians than girls of the same age. When the amount of walking is taken into account we find that boys and girls up to the age of 9 years have similar casualty rates per kilometre walked but boys are one and a half times more likely to be injured when crossing the road.

Throughout adulthood up to the age of 64, females have lower casualty rates than males, the rate for young adult females being half that for males of the same age. Older female pedestrians are as much at risk as children aged 5-9 years when walking alongside traffic and about the same as 10-15 year old males when crossing the road. Older females are two and a half times more at risk of injury than males of the same age for the same distance walked or number of roads crossed.

Just over half the pedestrian casualties occur on the main roads in Northampton but they only account for about 20 per cent of the total length of roads in the Borough and only 16 per cent of the walking of Northampton residents is alongside these types of road. For all residents of households aged 5 years and over the casualty rate per head of population indicates that the average person is just over twice at risk on the main roads as on the residential roads. However, when exposure is taken into account the relative risk is more than six times for walking

alongside main road traffic and more than nine times for crossing a main road.

3 Towards a safer road environment

The findings of studies of pedestrian behaviour have implications for policy decisions at both national and local level in regard to the provision of education and training for all road users, for enforcement, for the design and layout of new roads in urban areas, and the improvement of existing roads both in terms of management of both traffic and pedestrians and in changes to the road environment itself.

The study reported here highlights the implications for education and training of people of all ages, especially the young and those who are responsible for their safety such as parents and guardians, teachers and school governors. Far too many children and young people are injured whilst they are crossing the road so the challenge is for educators, planners and road safety professionals to identify locations and behaviours which can be targeted for remedial treatment. That children are walking less is of great concern to those responsible for promoting healthy lifestyles and transport policies. Children should be encouraged to walk more but this can only be achieved if the environment is improved to make it both safer and less threatening for children and their parents.

The older pedestrian is seen to be almost as much at risk as children and this is also an issue which needs addressing by education and training. The older age group has for too long been left out of the planning process. The older end of this age group is dominated by women as they tend to live to a greater age than men. These women tend to be frail and liable to severe injury when struck by a vehicle. They are much less likely than average to have had a car or driving licence thereby making it important both to understand their mobility problems and to work with them to make their trips to the shops, post office and elsewhere safe and with reduced threat from fast moving traffic (Carthy et al 1995).

People do one seventh of their walking on footways with cracked paving or badly worn surfaces. This is not a reflection on Northampton in particular as most urban areas suffer similar problems. However, there are implications for the ease of mobility for older pedestrians and those with difficulties going out on foot. Department of Trade and Industry figures suggest that up to ten times as many people attend Accident and Emergency Departments of hospitals with injuries sustained in falls on the footways and other transport areas as are injured in road traffic accidents (DTI 1990). Whilst it was not possible in this study to calculate casualty rates other than for road traffic accidents, investigation of other aspects of pedestrian safety are important when considering the pedestrian environment in its wider sense.

It is not just the older and younger pedestrians who are at particular risk as the study has highlighted the young adults, especially males. How to reach this group poses a challenge to educators at both local and national level.

Besides the age and gender differences the most important finding to emerge, and perhaps the one with the most far reaching implications, is that of the high relative risk of injury on main roads compared with local distributor and residential roads. In turn, the local distributors carry a higher risk to pedestrians than the residential roads. The problem is complex due to the interplay of function and use of these roads in providing routes for traffic to gain access to the commercial centre and to move goods and people from one part of the town to another. This conflicts with the needs of pedestrians to be able to cross the road safely without needing to walk undue extra distance or incur undue delay. Sixteen per cent of the walking and fifteen per cent of the crossings produce nearly 50 per cent of the casualties. Those with responsibility for the safety of the road environment need to work closely with the educators and Police to understand more clearly how to reduce the conflict between pedestrian and vehicular movement on this type of road in order to reduce risk to pedestrians.

The large differences in risk of an accident in daylight and darkness point to the need for further work to be carried out to increase our understanding of the difficulties encountered in darkness both by pedestrians and by other road users.

The amount of walking at different distances from home can provide input to the discussion on how planners and those responsible for the safety of the road environment enter into dialogue with people about different road safety problems and possible solutions to them. People's perceptions of their environment may well differ depending upon how familiar they are with it, which in turn may depend on the amount of walking and social interchange with neighbours. More work is needed to understand how people relate to different road environments. In particular the requirement for safe access for women and young adults needs to be addressed because these are the groups who walk the greatest distances. Also highlighted is the need for young and older people to have good, safe access on foot to the public transport system because the young do not have access to their own independent means of transport, nor do many of the older people.

This study has made an important contribution to increasing the understanding of the patterns of walking of pedestrians of different ages and gender in different parts of the road environment. Its findings can contribute to the discussion about the direction of future research into pedestrian safety and provides more information than was hitherto available to input to policy decisions about the safety of the pedestrian environment.

The study also provides a methodology to enable comparative studies to be undertaken to enable an exchange to made of more systematically collected information between regions or between countries. This in turn will enable good practice in relation to decisions about the pedestrian environment to be shared more widely and help us to put into perspective by the addition of exposure data the apparently poor pedestrian safety record in Great Britain compared with some other European countries.

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5 References

Carthy, T. Packham, D. Salter, D. and Silcock, D (1995) *Risk and safety on the roads; the older pedestrian,* (AA Foundation for Road Safety Research, Basingstoke)

Department of Trade and Industry (1990) *Home and Leisure Accident Research. Twelfth Annual Report: 1988 Data,* (Department of Trade and Industry, Consumer Safety Unit, London)

Department of Transport (1993a) *National Travel Survey 1989/91. Transport Statistics Report,* (HMSO).

Department of Transport (1993b) *Road Accidents Great Britain 1992,* (HMSO)

Department of Transport (1995) *National Travel Survey 1992/94. Transport Statistics Report,* (HMSO).

Hillman, M. Adams, J. and Whitelegg, J. (1990) *One False Move... a study of children's independent mobility,* (Policy Studies Institute, London)

Oxley, P.R. (1993) Special needs: a fairer opportunity for mobility, in P Stonham (Ed.) *Local Transport Today and Tomorrow*, (Local Transport Today, London) 61-65.

Ward H, Cave, J.A. Morrison, A. Allsop, R.E. Evans, A.E. Kuiper, C. and Willumsen, L.G. (1994) *Pedestrian Activity and Accident Risk,* (AA Foundation for Road Safety Research, Basingstoke)

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On a Partially New Approach towards Traffic Planning and Street Design in Sweden

In the middle of the fifties we decided in Sweden not to allow cars to drive faster than 50 kilometres an hour in our cities. We also decided that the exceptions to the speed limit mentioned above were to be very few. This decision was based on the fact that we wished to control an increasing car traffic, but also because of the fact that it was considered "comfortable" to drive the car at that speed because of the cars' construction. Earlier there was no speed limit at all for car traffic in towns.

But the streets, or maybe better "the public places" in a town, must meet a lot of different demands and wishes from the inhabitants. Of course it must be possible to go by car in the streets in a city, at least in most streets. But it must also be possible to go by foot, by bicycle and by public transport. The public places in a town have a great potential for planned and for unplanned encounters which should be made possible, and even enhanced, by the construction of the streets in a city. The public places in a town are open to everybody, including children, elderly and disabled people, and it should certainly not only be open to those who have a driving licence.

In Sweden we got guidelines for traffic planning in 1968 and in 1982. In both cases it was a clearly hierarchical division of the streets, but we kept the speed limit of 50 kilometres an hour for practically all streets, in contrary to what happened for instance in Holland and in Denmark.

In order to satisfy as many as possible of the different demands and wishes the inhabitants have on public places in a town, we now try a partially new approach towards traffic planning and street design. This means that we basically look upon speed as a very important and integrated factor.
From a traffic safety point of view it is briefly as follows:

- Where a car can hit a pedestrian or a bicyclist, the car is not allowed to go faster than 30 kilometres an hour
- Where a car can run into an other car's side, the car is not allowed to go faster than 50 kilometres an hour
- Where there is a risk for a head-on collision, the car is not allowed to go faster than 70 kilometres an hour

More or less as a logic consequence from the thoughts above we try to introduce a hierarchical division of streets and roads according to speed as follows

- 30 kilometres an hour streets for car trips within a district and for car trips to or from a 50 kilometres an hour street
- 50 kilometres an hour streets for car trips between quarters of the town, but when passing zebra crossings cars are not allowed to go faster than 30 kilometres an hour
- 70 kilometres an hour roads for long distance trips with car in a town, where no pedestrians and no bicyclists are allowed

Also we want to use

- 7 kilometres an hour streets ("woonerfs") for car traffic when going to a destination along the street or a street nearby, and of course we also want to use
- Lanes for pedestrians and bicycles (pavements, footpaths, squares, bicycle-lanes and so on where no motor vehicles are allowed - a domain for pedestrians and cyclists.

When a person is in a street she should be able to understand, preferable intuitively, what kind of street she is in, what traffic behaviour is expected from her and what traffic behaviour she can expect from others. For that reason the different streets must have clearly distinct designs. It must be obvious for a person what kind of street she is in, and it must be obvious for her what different kinds of qualities are given priority in the streets by its street design. For instance the accessibility of cars in 70 kilometres an hour roads, and considerations to children, elderly and disables in 7 kilometres an hour streets.

So these are **The five distinct different kinds of streets or lanes** which we want to work with in Sweden from now on.

I now want to describe the five levels more in detail - as a vision. I will begin with

1 Lanes for pedestrians and cyclists *(The car free area)*

It includes all the city's footpaths and bikeways, walkways, parks, recreation areas, market squares and playgrounds as well as all the neighbourhood areas where cars have been prohibited. The main goal is to interconnect as many as possible of the different parts of this area so that people as far as possible can walk or cycle in the car free area without having to confront the risks, conflicts and disturbances associated with motor traffic. Another goal is to expand the car free area.

The walking areas and pedestrian and bicycle paths have moderately steep inclines, surfaces are smooth and even, and the street furniture is well designed. There are attractive outdoor spaces protected from the natural elements for meetings, play and recreation. There are clear guidance markings, good street lighting as well as other design details that make everyone, including children, the elderly and disabled, feel safe and secure. Motor vehicles can be granted exemptions to enter the car free area, but only on the terms set by pedestrians and cyclists, the car is not allowed to go faster than a person walks, and that is something between 5 and 10 kilometres an hour, depending who walks, maybe as an average 7 kilometres an hour.

2 Woonerfs **(Pedestrian Streets, 7 kilometres an hour streets)**

is designed as communal outdoor space shared by everyone living on the street, it is a street especially for children, elderly and disable, and it provides very great potential to create an attractive, pleasant street space.

It is a street for car traffic when the car is going to a destination along the street or a street close nearby. This type of street has often been created on the initiative of the property owners and the local residents, and both parts support the implementation and maintenance operations. This type of street is not divided into separate lanes for different types of traffic. The street has been designed and regulated so that the maximum speed for cars does not exceed walking speeds, which is something between 5 and 10 kilometres an hour, depending who walks. Pedestrians always have the right of way. In the year 2010 we think woonerfs will constitute 20-25% of the street network.

3 (Local) *Residential Streets* (30 kilometres an hour streets or 30/30 streets)

are also included in the local street network and are used only by local bicycle and car traffic that has its origin or destination in the neighbourhood. There is more car traffic here than on woonerfs due to the fact that there are more houses and buildings, shops, offices, etc. Furthermore, the residential street provides great potential to create an attractive, pleasant street space and an environment suitable for children, the elderly and the disabled.

Pedestrians and cyclists can arbitrarily cross a residential street either anywhere along the street or at street crossings. There are thus no marked pedestrian crossings, bicycle crossings, bicycle paths or traffic signals in a residential street. Traffic calming measures guarantee the safe and secure interaction between pedestrians, cyclists and motorists. In the inner city areas, residential streets provide for part of the need for short-time parking. Parking spaces have been designed and located with care and are aesthetically attractive in the street environment.

In the year 2010 we think residential streets will constitute 25-30% of the street network.

4 Main streets (50/30 streets)

can serve several traffic functions. A main street has often local traffic and collector traffic, sometimes there are also some through traffic or access traffic.

The carriageway has only one traffic lane in each direction for cars, and the volume of car traffic is thus limited to some 1 500 vehicles per design hour. There is a special bus lane on main streets with heavy bus traffic. There are both wide bicycle lanes and wide walkways on main streets affording cyclists and pedestrians good accessibility, safety and security. Furthermore, these areas provide the potential to create an attractive, pleasant street space and an environment suitable for children, the elderly and the disabled.

Destination points in the surroundings are concentrated together and located so that pedestrian and bicycle traffic needing to cross streets can be steered naturally to specific intersections. These are designed so that cars cannot drive through them at speeds exceeding 30 km/h. This ensures a safety level comparable to that on 30 streets.

Where the situation demands, and where the city plans permit, the main street has a central reserve with a safety fence to ensure that pedestrians and cyclists only cross the street at designated places. Marked pedestrian crossings are designed with children, the elderly and disabled in mind. On stretches where there is no crossing pedestrian or bicycle traffic, cars are permitted to drive a maximum of 50 km/h.

There are special areas for loading and unloading on main streets but as little curb-side parking as possible.

The streets, terminals and parking spaces within the residential and main streets are designed so that pedestrians and cyclists are given as much space as possible, while the area for car traffic is limited in line with the purpose of the street traffic.

Based on the street surroundings and the purpose of traffic, the streets within the residential and main streets are classified according to the desired speed and the degree of segregation that this speed demands. The street design also means that the flow of traffic is limited with respect to the demands inherent in the purpose of the traffic. From a traffic safety point of view, speed is the most important criterion, and the types of street are designated according to the standard of speed desired.

In the year 2010 we think that main streets will constitute 20-25% of the street network.

5 Traffic Routes (70/50 roads or 70 roads)

Traffic routes has thoroughfares traffic, access traffic and through traffic. These streets are segregated from pedestrian and bicycle traffic and any road connections to adjacent neighbourhoods are intended for car traffic only. There are mainly two types of street: 50/50 streets and 70/50 streets. Some traffic routes are for 70 or 90 kilometres an hour traffic. The alignment is of high standard and the distances between intersections are sufficiently long with respect to the intended speed level. Furthermore, there is no parking permitted on traffic routes.

Traffic routes are situated further away from buildings and the distances between intersections are longer. There is roadside space available to enhance the safety of errant vehicles. The speed limit is mostly 70 km/h on unbroken stretches and 50 km/h through intersections. Due to the longer distances between intersections, the accessibility gains on the 70 km/h stretches are more obvious. Despite the higher speed level, the environmental impact on the surroundings is moderate due to the greater distance to houses and buildings.

Rigid, stationary objects in the roadside areas have been either positioned, designed or shielded so as to protect motorists from serious injury in the event of head-on or side collisions when unintentionally driving off the carriageway.

The speed at intersections may not exceed 50 km/h if there is any chance of side impact collisions. This is ensured through traffic calming design measures or, ultimately by using RTI technology.

The speed on 50/50 streets is 50 km/h both on unbroken stretches and at intersections. These streets are situated close to buildings which often means that the roadside area cannot fulfil the clear roadside concept. Thus, great care is placed on the design and positioning of poles and other rigid, stationary objects that of necessity must be located at the side of the street. The speed limit is ensured through a traffic calming design, even on unbroken stretches. The low speed here is accepted by motorists because higher speeds would only have a marginal time-saving effect due to the relatively short distances between intersections. The speed limit is also felt to be well motivated due to the close proximity of housing developments.

The thoroughfares consists of those streets and other traffic facilities where priority is given to the efficient transport of people and goods by car at steady, moderate speeds within a street and road network capable of handling the prevalent traffic volume. The good accessibility offered to motorists within the motor transport space is perceived as so advantageous that they choose this network for everything except the shortest local trips. There are no pedestrians or cyclists in the traffic routes. These vulnerable road-users have been provided with grade-separated interchanges for crossing the

motor transport space. For movement parallel to the motor transport space network, there are pedestrian and bicycle paths that have been totally segregated from car traffic by vegetation or safety fences.
In the year 2010 we think that traffic routes will constitute 10-20% of the street network.

Design criteria for urban roads and the need of research

We are now concentrating our work to find the "right" design and lay out for each of the street categories; woonerfs, residential streets and main streets.

The main purpose with a ***woonerf*** is as a communal outdoor space shared by everyone living on the street. It is a street especially for children, elderly and disable, and it provides very great potential to create an attractive, pleasant street space.
How can we by the design, layout and materials of the street communicate the message above to (as far as possible) everybody in the street?
We think that it is important that a woonerf is not divided into separate lanes for different types of "traffic". The same surface is used for children's play, grownup's talk, pedestrians, cyclists and car traffic. We also think that it is important that woonerf has a design and layout and is regulated so that the maximum speed for cars does not exceed walking speed.

A residential street is a street in a residential area. In a residential area is given priority to the inhabitants in the area. The normal way to move within a residential area is for most of us by foot or by bike, for others with help of a stick or by "rollator" or in a wheelchair. Young parents often have a pram.
Within a residential area it is of course natural to cross a street as a pedestrian or a cyclist arbitrarily either anywhere along the street or at street crossings. For that reason there are in a residential street no marked pedestrian crossings, no bicycle crossings, no bicycle paths and no traffic signals. The street is as small as possible, something between four and six meters, thus the pavement is as broad as possible witch provides great potential to create an attractive, pleasant street space suitable also for children, the elderly and the disabled.
Traffic calming measures guarantee the safe and secure interaction between pedestrians, cyclists and motorists. One good traffic calming measure is an elevated crossing, signalising that in residential areas one gives priority to pedestrians. This solution will help elderly people to move, especially those in a wheel-chair and those with a pram. Another god solution is using a roundabout.

But we need more good solutions for streets crossings in residential areas.

The most important purposes with a ***main street*** is to enable for the busses, the car and the bicycle traffic to go from one part of the town to another, adjacent or near by. But a main purpose is also to enable the pedestrians and the bicyclists, children, elderly and the disable, to cross the main street safe and secure. For that reason it will not be allowed to cross the pedestrians crossing and those for bicyclists faster than 30 kilometres an hour. For that reason there must be some traffic calming measure connected to the pedestrian and bicycle crossing, also make it reasonable convenient for buss passengers. It will not be allowed for pedestrians and cyclists to cross a main street elsewhere than on pedestrian and cyclists crossings. A very important though about the main street is that we will not allowed the carriageway to have more than one traffic lane in each direction for cars. And the same is for roundabouts; only one lane for incoming car traffic, only one lane in the roundabout and only one lane for outgoing traffic. The carriageway is 6 to 6,2 meter broad.

Of course we are not quite sure that the suggestions mentioned above are good solutions in every details, on the contrary a lot of work is ahead of us. But all the same, already next year we hope to be able to build some projects - probably between five and ten - containing some woonerfs, some residential streets and some main street for research and developments, and hopefully also for demonstrations.

URBAN PLANNING AND TRAFFIC SAFETY

Stjepan Kelčec-Suhovec

1 Introduction

Behavioural, environmental and vehicle problems prepare the ground for unsafe situations in traffic. Mostly they act in combination. Environmental problems inside settlement, related to traffic safety, sometimes have roots deep in urban planning.

The objective of this article was to analyse circumstances in the process of urban planning, designing and construction of streets that might contribute to higher risk in traffic, describing two cases in the city of Zagreb.

2 Sequence of green squares

In the nineteen century inside the city center a lovely sequence of three green squares was built up, from main city square to main railway station /part of so called green horse-shoe/. The squares are situated in a grid of street network and up to date are very appreciated as the most beautiful urban planning creation in Zagreb.

In Zagreb Master plan 1936 the idea of extension appeared - new green squares from railway station southward to the river Sava, as extension of previous three squares /figure 1/. A little bit transformed idea was realized after second world war in the sixties and seventies. In fact, a new avenue was built up with dual carriageways and green area between them. By the bridge, the avenue was spread to the right bank of the river Sava. Green area was 50 to 60 meters wide and altogether with carriageways and pedestrian footpaths the avenue width was 80 to 110 meters.

Three new intersections with main city streets were built up in that avenue. The layout of carriageways suggested four armed split intersections and traffic planners accepted that type because it fitted in general idea of squares and had high traffic capacity. The intersections were equipped with traffic lights. But year by year the number of accidents indicated safety problems related to these intersections. The first of them was reconstructed in 1978 and transformed in two level junction. The second one was reshaped in 1985 into a single four armed intersection. The third one is waiting for a final decision.

After reconstruction in the both cases the level of safety was improved. Precisely, after reshaping split intersection into the single intersection the improvement of 60% was recorded when compared the number of conditional traffic accidents-PDA in the time period of five years before and four years after.

Small intersections in green squares inside the city center did not indicate higher number of

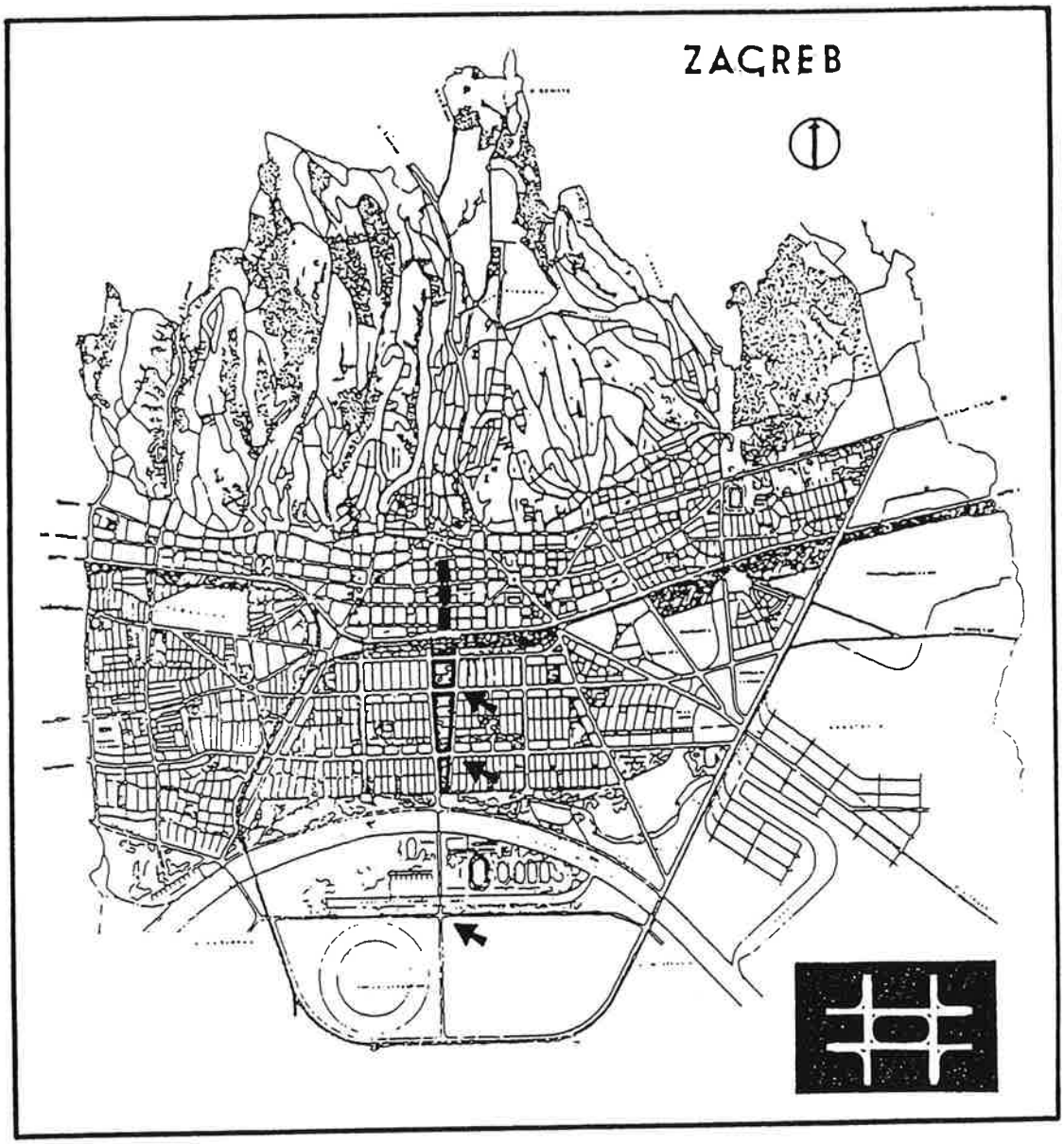


Figure 1:
Zagreb master plan 1936, basic idea of new green squares - bolded, old squares in the city center - black spots
Bottom right - type of intersection built in 1960s and 70s, positions indicated by arrows

accidents compared to the similar intersections in city center but idea of green squares transformed into new avenue with split intersections and entirely different role in traffic network showed higher accident risk. The results after the reconstruction showed that previously chosen type of intersection was not the best solution in Zagreb's circumstances. Split intersection confused left turning drivers and they caused a lot of right angle and rear end collisions.

3 Residential zone

Residential zone Španska and Malešnica in Zagreb was planned in late 1970s and mainly built up in 80s. It takes area of approximately 2 square km and is 6 km westward from city center. Prevailingly the zone comprises high rise and low rise apartments.

Higher risk in traffic was noted inside the zone so the research was undertaken in 1993. As regards traffic accidents, the time period of three and half years was analyzed, vehicle speed and traffic flows were measured and inhabitants interviewed on general quality of life inside the zone.

Research found out:

- the quality of life inside the zone is acceptable in general, the zone is well equipped as regards green spaces and pedestrian surfaces but pedestrian flows are threatened by motor vehicles, predominantly at intersections /the same meaning was expressed by experts and by interviewed inhabitants/,

- during the analyzed time period fatalities were not recorded but a lot of property damage accidents and causalities. Vulnerable participants in traffic, pedestrians and cyclists, took part of 25% of casualties,

- accidents were predominantly grouped at intersections and alongside certain street in N-S direction and

- a remarkable amount of through traffic and speeds over the limit were recorded.

The proposed measures for improving safety were:

- lower speed limits,
- redesign of certain intersections and
- redesign of some pedestrian zebra crossings out of intersections.

Lower speed limits were introduced and a few points were redesigned, and that has shown some results but a complete evaluation has not been done so far.

Let us skip back now to the idea of street network related to that zone in Zagreb master plan. Two major streets in E-W direction were planned, as well as one major street at the east and one at the west edge of the zone. The zone was built up, but the street network was built only partially. The major streets in N-S direction were not realized at all, and the major streets in E-W direction were built up but only inside the zone, without any direct connection to the city network /figure 2/. A minor street network was realized consequently.

Caused by these facts, the motor vehicle traffic flows were turned upside down and the role

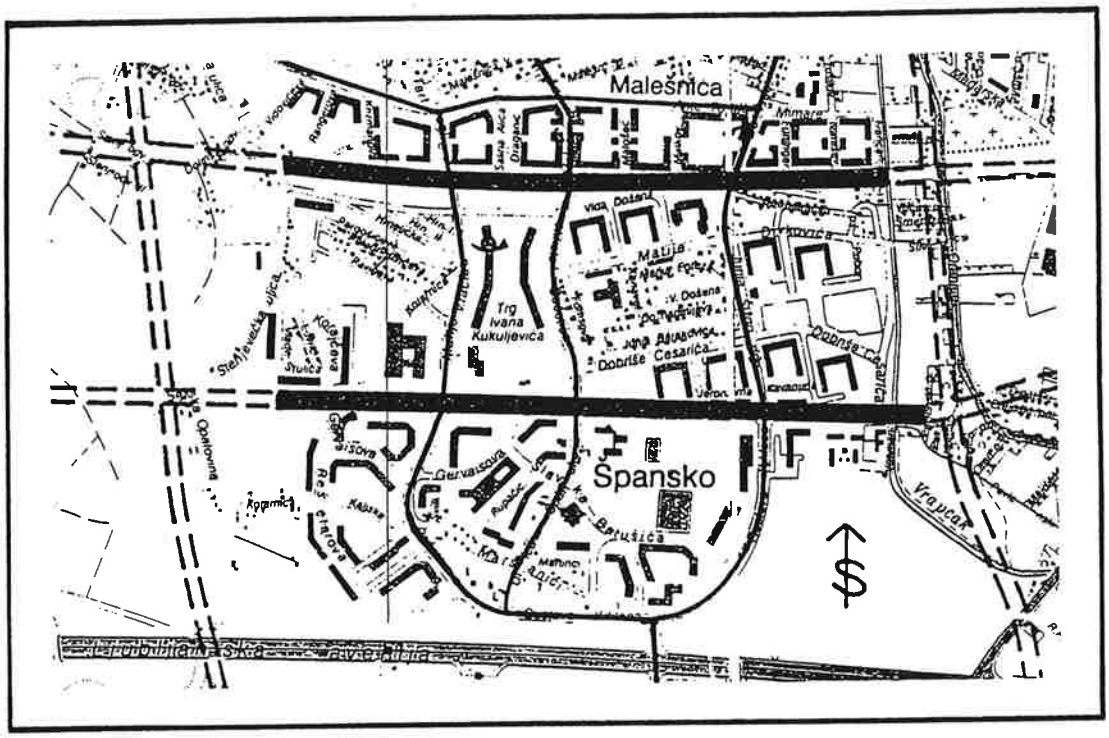


Figure 2:
Špansko and Malešnica residential zone

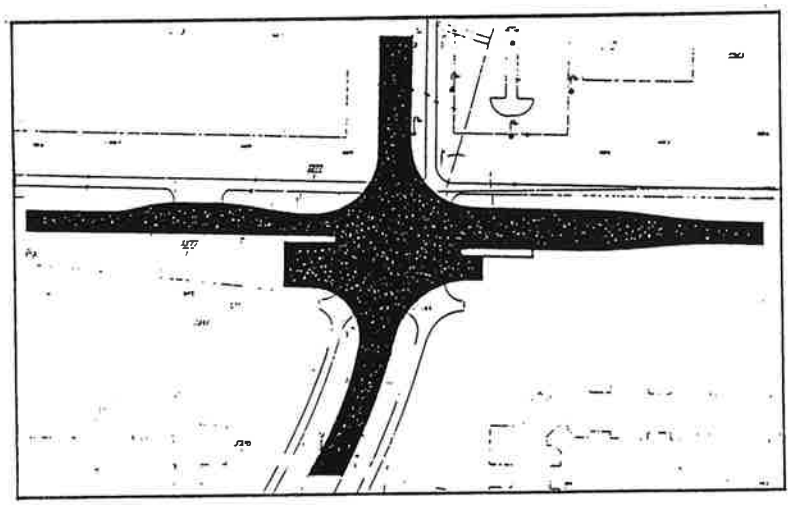


Figure 3:
Intersection in major street

of streets was changed. A minor street in N-S direction comprised a high proportion of through traffic and as a consequence there were more speed limits violations. The major streets in E-W direction had the role of minor access streets.

The intersections in the streets were built with dual carriageways and the storage lanes, in spite of the fact that sections were built with just one carriageways /figure 3/. In addition to that, the high curb radii /up to 25 m/ made intersections geometrically very spacious, not convenient for pedestrians, and confusing for drivers.

That background comprises the elements of high importance regarding to the latter traffic safety problems.

4 Conclusion

The type of intersection was chosen in accordance with suggestion of general layout of avenue carriageways dictated by idea of extension of green squares in city center. That choice was not the best one from the traffic safety point of view and two intersections have been reshaped so far.

Residential zone was planned and designed when the idea of traffic calming did not exist in Croatia. Contrary to that, planners believed that all problems in public transport were going to be solved by the private cars. Consequently, the street network and its geometrical elements were planned. In the period of construction, the major streets were built just partially, with strange intersection geometry. Both contributed to the later traffic safety problems.

5 References

1. Razrada koncepta smirenog prometa i njegova primjena na jednu izrazito incidentnu zonu u gradu Zagrebu /Concept of Traffic Calming and Its Implementation in Markedly Conflict Zone in the City of Zagreb/, PROMETIS, Zagreb, 1993.

2. DIVIĆ A., SMRČEK A., ANŽEK M.: Utjecaj oblikovanja križanja na sigurnost prometa /Influence of Intersection Configuration on Traffic Safety/, Ceste i mostovi, 3-4, pp 81-87., Zagreb, 1995.

3. ZAGREB MASTER PLANS 1936, 1971, 1986 and urban planning documentation, City Bureau for Development Planning and Environmental Protection Zagreb - archives.

4. GLEDEC M.: Sigurnosni aspekti tehničkog uređenja prometa /Safety Aspects of Traffic Control/ Ministry of Interiors, Croatia, Zagreb, 1997.

5. POLICE REPORTS ON ROAD SAFETY

Ralf Risser

Can one make walking and cycling more attractive without causing safety problems?

1. Introduction

WALCYNG[1] was a project carried out in the 4th framework programme of the EU, in the area of Urban transport (DGVII). Measures should be developed in order to convince people to walk and to cycle instead of using the car for short trips (> 5km for cycling, > 1km for walking).

2. The marketing approach

A marketing approach was chosen to do this work (for a general overview over the concept of marketing see Kotler et al. 1996). The consortium, consisting of partners from eight European countries, started by surveying what products exist and what efforts are made for walcers[2] . Partly, a check was made to see how many potential walcers exist in Europe (i.e., how many people use their car for journeys of less than 5km). The next step was to compare the features of the listed products and efforts to the features wished for by the potential walcers. This was done partly on a more theoretical basis - by studying literature on the topic - and partly by interviewing potential walcers. In addition, we also interviewed practicing walcers:

Our assumption was that walcers would tell us about their experiences, whereas potential walcers would tell us their assumptions, prejudices or stereotypes. Critical comments from walcers could lead to products´ or efforts´ adjustment and/or improvement. Critical comments from potential walcers would have to be answered by adjustments and/or improvement of communication and advertising.

3. The most relevant user needs

More precisely, we should talk about the most relevant motivational aspects for users and potential users. The table below shows what aspects associated to walking and

TABLE 5: ***DISADVANTAGES AND ADVANTAGES OF WALCYNG SEEN FROM THE CUSTOMERS' PERSPECTIVE***

road users	advantages of cycling	disadvantages of cycling	advantages of walking	disadvantages of walking
car drivers	• cycling is fun • it is healthy • you get fresh air	• you cannot carry heavy things • the cycle network is incomplete • you depend on good weather	• it is healthy • it is environmental friendly • you get fresh air	• it takes a lot of time • you cannot carry heavy things • you depend on good weather
walcers	• you are flexible and independent • it is healthy • it is economically efficient	• the cycle network is incomplete • high speed of car drivers • lack of secure parking	• it is healthy • you get fresh air • easiness (no parking problems, etc.)	• it takes a lot of time • you cannot carry heavy things • feeling of insecurity during night time

[1] WALking and CYcliNG instead of short cor trips
[2] „walcers" is a word for „walkers" and „ciclists"

cycling are considered positively, and what aspects are considered as difficulties. "Difficulties", in the case of walcers, make life difficult, and in the case of potential walcers, they deter from walcyng.

Hakamies-Blomquist (1996) concludes from literature studies that the following aspects are relevant for walcers from a motivational point of view:

- A problem related to *Social Values* is the low status of walcyng, especially when compared with driving a car. Also, the nature of the interaction between different road users is highly influenced by social attitudes.
- *Health:* Cycling is good for the health but cannot be done without good basic health.
- A*estetichal problems* evolve as pedestrians and cyclists have time to look around and really get to know the environment. A green environment is particularly valued. Noise from surrounding traffic and pollution are experienced as aesthetic *and* health problems.
- *Comfort:* Since walking is not only a means of transport, but also a way of socialising etc., it is important that there is special provision of benches, waste-baskets, shelters and public toilets, etc.
- The main *Mobility problem* of cyclists is the lack of a continuous and good quality cycle path network.
- *Security:* Security (= experienced safety) does not always correlate with objective safety. To increase the experienced safety of walcers, cyclists should be separated from cars, and pedestrians should be separated from both cars and cyclists. On the other hand, personal security is threatened if walcers are too isolated, especially if the illumination is not sufficient.
- Unlike car drivers, walcers are in many countries not offered any financial support. Moreover the relative inexpensiveness of cycling is threatened by bicycle theft.

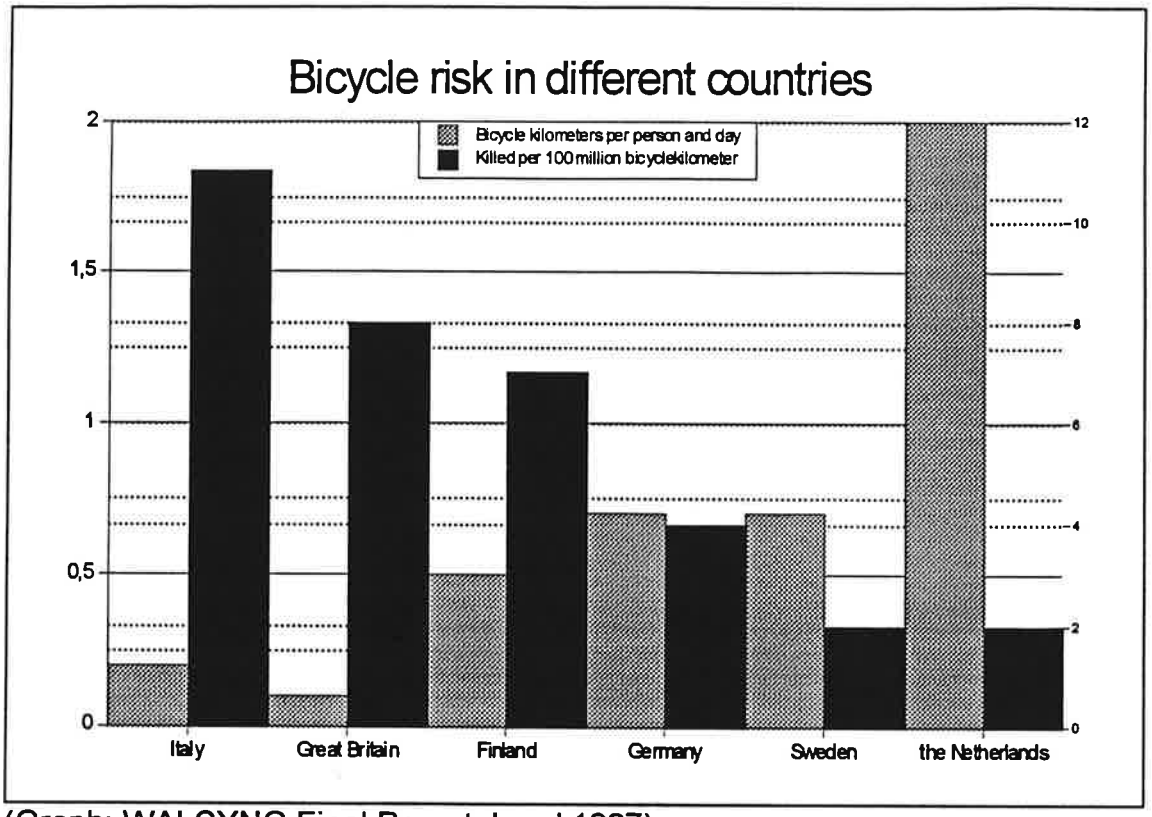
4. The role of safety

Safety as it is seen or experienced by the user, was called security in the WALCYNG work, and refers to what is, in the literature, sometimes called subjective safety. However, the discussion here does not loose in accuracy, if we simply talk of „safety".

Obviously, lack of safety is not felt so strongly by walcers nor by potential walcers and thus, safety issues do not get number 1 priority. However, safety is a problem for the authorities: The individual risk for walcers is rather high when compared to the individual risk of car drivers. It would, of course, be a problem, if one made a lot of people change to walcyng instead of driving a car and then accident numbers were to go up.

There are some results that indicate that, without any extra precautions, accident numbers would not go up linearly if the number of walcers increased considerably (Pasanen 1996, Ekman 1996; see table below).

Moreover, there is an indication that there are safety enhancing measures for walcers that would, at the same time, make walcyng more attractive.



(Graph: WALCYNG Final Report, Lund 1997)

5. How to make walcyng more attractive and safe

Many elements of the traffic process are relevant for walcers´ safety. I want to address three of them that have been considered as having high priority and to show that shaping them in a way that leads to better safety could also improve attractiveness of walcyng:

1. The interaction between pedestrians and cyclists
2. The interaction between motorised car traffic and walcers
3. Vehicle speeds

5.1. Interaction between pedestrians and cyclists

It has been shown that many minor accidents result from the interaction between pedestrians and cyclists (see Pasanen). This problem, however, is to a large degree the consequence of lack of space for these two groups so that they have to share the same areas, often under very restricted conditions. Giving walcers more space would allow better separation between the modes and thus not only improve safety, but also the attractiveness of walcyng.

5.2. Interaction between cars and walcers

Many accidents between cars and walcers occur where cars are turning left or right, thereby crossing walcers' paths. In WALCYNG it has been argued that car drivers are not afraid of walcers. Nobody really wants to knock down a walcer, but, nevertheless, the lack of any threat for the car drivers in their interaction with walcers facilitates nonchalant behaviour. *Technical measures that provide as low a speed as*

possible at places and on along routes where car drivers have to interact with walcers seem to be the only reasonable solution of these problems: humps, elevated intersection areas (one could call them „interaction areas"), mini-round abouts, etc..

Another most important aspect that has been mentioned in WALCYNG is *good visibility* at interaction areas.

Both types of solutions provide better safety and, at the same time, they make walcyng more attractive:

- crossing roads becomes easier
- walcyng becomes more undisturbed
- waiting times for walcers become shorter
- communication between car drivers and walcers is fairer
- more equity between walcers and car drivers is provided.

5.3. Vehicle speeds

One main element of unsafety in the traffic process is vehicle speed (e.g., Varhelyi 1996). It especially affects the degree of severity of accidents (Pasanen 1992).

At the same time, vehicle speeds are mentioned by walcers as a very disturbing factor, and even as a barrier for walcyng (see table above; Risser & Ausserer 1997). Thus, a reduction of vehicle speeds in areas where walcers and other vehicles have to interact would improve both safety and the attractiveness of the traffic environment for walcers. It is not, therefore, a reduction of speed limits that is the main goal but "cutting off" speeds above the limit and, most of all, top speeds: speeding in inhabited areas should become impossible.

6. How to achieve better interaction and lower speeds

It has already been mentioned that in order to improve interaction between walcers and motor vehicles, the speed of cars has to be adapted better to walcers' speeds. Measures to achieve this are humps and/or elevated intersection levels. Mini round abouts also reduce speeds at such places where road users have to interact with each other (Hydèn et al. 1995). Flattened slopes at curbs combined with reduced road width at intersections make life easier for walcers at these points and have a speed reducing effect, thus improving safety. All this makes crossing the road for walcers easier, more comfortable and safer.

One measure for area-wide speed reduction, or better, speed control is movable speed-control equipment (where speeds are measured from a car; Pasanen 1996); another one is the speed limiter which is, as we speak, being evaluated (see Almquist & Nygaard 1997).

7. Travel times

Lower car speeds may lead to longer travel times. On the other hand, at cross roads the situation for one part of the car drivers will certainly improve, e.g., those who do not have the right of way: It will be easier for them to enter main roads and probably travelling times will be reduced as far as this type of interaction between car drivers is concerned. This has not been very well calculated, yet. Moreover, we do not know of any analyses of travel times of walcers under different car-speed conditions. It is

quite possible that there will be no time losses at all, if one takes the whole population viz. all the road users' travel times into consideration.

A perspective on safety work

From what has been said above, one can conclude that both walcers and potential walcers, precisely as people in general, behave in order to fulfill needs, or in order to avoid frustration. In this connection, safety does obviously not play a very important role: Walcers do not complain about any lack of safety, and potential walcers do not seem to be especially deterred by safety problems. However, safet, or the lack of it, is a societal problem. Thus, it seems that shaping conditions for walcyng with respect to other motives than safety is a the most promising way to influence users´ and potential users´ behaviour. Thereby, from a societal point of view, it has to be seen to it, that safety is improved. If walcyng is fun and, at the same time, safe, everybody will be happy in the long run.

One could dare to predict that traffic safety work will move in this direction, generally: Behaviour will be influenced by making road users both strive for reinforcement and avoid negative stimuli that are not directly related to safety aspects, but rather to other motives. Safety work will be done without referring to safety in one´s practical work and in one´s communication with the public, whereas evaluation work will, among others, of course be based on safety criteria. Safe behaviour will be sold as being fun, which will show in the accident statistics.

References

- Almquist S. & Nygaard M. 1997, Demonstrationsförsök med dynamisk hastighetsanpssning i tätort, Delrapport i Program för Väginformatik, Publikation 1997:19, Swedish National Road Administration and Lund Institute of Technology, Department for Traffic Planning and Engineering
- Ekman, L. 1996, On the treatment of flow in traffic safety analysis - A non-parametric approach applied on vulnerable road users, Bulletin 136, Department of Traffic Planning and Engineering, Lund Institute of Technology
- Hakamies-Blomqvist, L. & Jutila U. 1996, General problems of pedestrians and cyclists: Report from WALCYNG - WP 3, Helsinki
- Hyden Ch. & Nilsson A. 1996, Products and efforts for walking and cycling: Report from WALCYNG - WP 2, Lund
- Hydèn Ch., Odelid K. & Varhelyi A. 1995, Effekten av generell hastighetsdämpning i tätort. Resultat av ett storskaligt försök, Lund University, Lund
- Kotler Ph., Armstrong G., Saunders J., & Wong V. 1996, Principles of Marketing, Prentice Hall, Glasgow
- Pasanen, E. 1996: Safety problems of pedestrians and cyclists: Report from WALCYNG - WP 4, Helsinki
- Pasanen E. 1992, Driving speeds and pedestrian safety. A mathematical model, Helsinki University of Technology, Publication 77, Otaniemi
- Risser R. & Ausserer K. 1997, WALCYNG, How to enhance WALking and CYcliNG instead of shorter car trips and to make these modes safer, Workshop in Braga, FACTUM, Vienna

- Varhelyi A. 1996, Dynamic speed adaptation based on information technology. A theoretical background, Department for traffic planning and engineering, Lund Institute of Technology

Simulation of "Driver - Vehicle - Road - Environment" Systems

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Abstract:

The general procedure of constructing the "driver - vehicle - road - environment" virtual systems was developed. Our operating experience with the virtual systems shows that the problems of automobile transport may be adequately solved for all practical purposes (traffic safety, roads operation and design, traffic engineering and control, environment protection, road data bank construction, transport policy, etc.).