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CONTENTS .... PAGES

CROATIAN PENAL SYSTEM LAW ON THE ROAD TRAFFIC SAFETY, Ante Divic, Ivan Stanko, Branko Pamic

Ministry of the Interior

Zagreb

Summary

This paper deals with changes and amendments of the Law on the road traffic safety that reflect in a reduction of the speed limits, in more severe penalty politics toward the offenders, in introduction of the penalty points into the penal system, and it also reflects in application of the above mentioned measures, and in wider police enforcement authorities in application of the above mentioned measures. These new measures are the result of the adopted suggestions, recommendations, positive experiences and researches conducted in the countries with more developed traffic safety systems.

During a short period of three months, suggested and adopted changes showed a visible and qualitative shifts in rising of the level of the traffic safety situation in Croatia.

1. Introductory remarks

The Law on the traffic safety presents the most important source of the road traffic law. In a direct application of the Law, it was observed that a number of existing solutions do not contribute to the safety improvement in a satisfactorily way, while at the same time the traffic safety situation was at inadequate level. This led to the changes and amendments in the Law, for which there were several basic reasons, as follows.

The first reason was the traffic safety situation on the Croatian roads. Namely, about 60.000 traffic accidents are registered every year in Croatia, involving, in average, about 18.000 injured persons, including more than 800 killed ones. The most frequent failure causing the traffic accidents is unlawful speeding, or speeds not adapted to the roads conditions, in which the drivers participate with about 35%. With a mean number of 95 killed persons per 100.000 registered vehicles, that is, 17 killed persons on 100.000 inhabitants, Croatia is at the European top of the unsafety scale.

Then, the next reason was implementation of measures and activities included in the National programme for safety in the roads traffic established by the Government of the Republic of Croatia by the middle of the year 1994.

It was also necessary to coordinate certain legal provisions with a more contemporary and more qualitative solutions existing in the countries of the European community.

Practice showed that a mild penal politics led to the situation in which a large number of participants in the traffic deliberately violated the traffic regulations and rules. Such undisciplined behaviour of the drivers reflected on the traffic safety situation.

That is why we started, by the beginning of 1995, with a draft of changes and amendments of the Law on the road traffic safety. A basis for this draft of a new law, and for shaping of changes and amendments, were analysis of the traffic safety with assessments of influence on all factors built in the road traffic safety, and on evaluation of the judicial practice and efficiency of the judicial bodies. Positive experiences and the legal regulations of the Western European countries (Germany, Austria, Italy, Spain) as well as experiences of the professional and scientific institutions and other ministries in the Republic of Croatia were taken into account as well.

2. Violations of the law - novelties

Changes and amendments on the Law implied focusing of the cutting edge of responsibility on the most important factor in the road traffic safety - on a human being factor, namely, on the participants in the traffic, especially to the drivers of the motor vehicles who intend to participate in the traffic respecting the regulations, and to bear serious consequences for own inadequate and unlawful behaviour.

Therefore, the starting point of this changed law is a hope that more severe repressive system would influence not only individual driver's behaviour, but that would bring about rising of the safety level as well.

Suggested essential changes could be expressed as follows:

A. Decrease of the speed limits

B. Introduction of the penalty points system

C. Wider authorities of the police in application of the special safety measures

D. Introduction of new special safety measures

E. More severe penal politics.

2.1 Decrease of the speed limits

A part of the Law dealing with the speed limits for certain traffic roads and certain categories of vehicles, the changes are reflected in the speed limits reduction for 10 km/h in urban/settled traffic roads and outside of the settlements. This change was done according to the World Bank recommendation at the seminar on the "Politics in the area of the road safety" held in Budapest in October 1994, and according to those given by the World Organization for Prevention in Traffic, PRI.

Thus, the speed limits in the urban areas were reduced from 60 km/h to 50 km/h with open possibility to increase the speed limits on the roads in settled areas up to 80 km/h, depending on the technical and safety elements that enable it (. pedestrians roadways physically separated from the traffic flows for vehicles with overpasses and underpasses, with more traffic flows in one direction, semaphored traffic regulation and so on). The speed limits were also reduced on the country roads (outside the settlements) that are not in the highway category or which are the roads intended for the motor vehicles traffic.

2.2 Introduction of the penalty points system

Using benefits from experiences of other countries, especially regulations from Italy, Germany, Greece, France, Canada, Victoria, most USA countries, and adopting recommendations of the World Bank and the European Bank for Reconstruction and Development and PRI, for the first time the penalty points system was introduced in Croatia, adjusted to our circumstances, providing for the offenders, besides the fine, a number of the penalty points. According to the Law, the penalty points are specified for about 60 serious traffic offences, out of a total of 300 offences covered by the Law.

Depending on a seriousness of the offence, the Law defines the following:

- one penalty point -. for overspeeding of 10 km/h to 30 km/h in urban traffic, or 30 km/h to 50 km/h outside the settled area, for taking over in front or at the pedestrians crossing, for failing to allow passing through a pedestrian at the pedestrians crossing and similar;
- two penalty points -., for disrespect of the red traffic light, for not allowing passing through to another vehicle, for non-compliant with the traffic sign or the policeman order, and
- three penalty points -. for overspeeding more than 30 km/h above the prescribed speed in a settled area, or more than 50 km/h outside the settled area, for driving under influence of alcohol, an so on.

However, if an offence caused a direct danger of the traffic accident, two more penalty points are added to the basic number of the points for such an offence.

Penalty points are summed up for a two-year period, beginning from the first registered penalty point. Each penalty point is erased from the penal record during a two-year period, starting from the date of its recording or after a period of temporary deprivation of the driving licence is expired.

Appropriate legal measure is applied on the basis of a number of collected penalty points.

A driver who in a two-year period collects five penalty points will be called by the Police administration, that keeps his records, to attend the lectures and watch the films on the consequences of traffic accidents. If he fails to attend the lectures, he would be punished with a fine of 500 Kuna (140 DEM) and he would be temporary deprived from his driving licence as well.

A driver who collects seven penalty point during the first two years since the first recorded offence, will be deprived of his driving licence for a period of 90 days. In such a case, the driver would be given back his driving licence only after he passed the testing in the traffic regulations knowledge. A driver-recidivist will be deprived the driving licence for a double period of the above mentioned time.

2.3 Wider authorities for the Police in applying special safety measures

With a purpose to improve efficiency of undertaken measures against offenders, the law provides for a deprivation of a driving licence on the spot by a policeman for four categories of the traffic offences. Only the penal measure is expired, after 90 days, such an offender can get back his driving licence.

The law precisely defines cases in which a police officer is authorized to take away the driving licence for a three-month period on the spot, as follows:

1. A driver who drives faster than 50 km/h in a settled area will be temporary deprived from his driving licence
2. A driver who drives under the influence of alcohol (more than 0,5 g/kg or pro milles detected in his blood test)
3. A driver who refuses to get submitted to the breath-testing
4. A driver who, after being involved in a traffic accident, leaves the scene of the accident.

2.4 Introduction of special safety measures

The law provides imposing of a safety measure of inhibition to drive a motor vehicle during one month period, but in these cases the driving licence is not taken away on the spot. This measure is imposed for the cases when

- the driver drives faster than the permitted 30 km/h to 50 km/h in a settled area, that is, faster than the prescribed speed limit outside the settled areas.;
- the driver drives contrary to a traffic sign or regulation;
- the driver does not stop his vehicle at the red traffic light;
- the driver takes away advantage of passing from another vehicle.

2.5 More severe penalty politics

The law provides for more severe fines for violators of the traffic regulations. The old law prescribed fines ranging from 7.5 Kuna to 175 Kuna (2 to 50 DEM) for the physical persons. New, changed and amended law provides for the traffic regulations offenders fines ranging from 50 Kuna to 500 Kuna (14 to 140 DEM), which presents an increase of 7 to 10 times. The fine of 4000 Kuna (1150 DEM) is determined for the traffic offences that caused direct danger or an accident.

The fines of 50 Kuna (14 DEM), 100 Kuna (28 DEM), 150 Kuna (42 DEM) and 200 Kuna (56 DEM) can be charged by a police officer on the spot. Higher fines are charged during the magistrates' court procedures.

3. The law implementation results for the first three-month period

Although suggested and adopted in a very short period of time, these measures showed obvious and qualitative shifts in the improvement of the traffic safety situation in Croatia.

Achieved affects can be considered through the prism of a number and consequences of the traffic accidents, as a qualitative indicator of the safety situation. Thus, from 1 July to 30 September 1996, during the first three months of implementation of this new changed and amended law, and compared to the same period in last year, we established the following indicators:

- there were 1.568 accidents less than last year (July - 6%; August - 8%; September - 12%);
- there were 41 persons killed less than last year (July - 0%; August - 30%; September - 8%);
- persons less than last year were injured (July - 8%; August - 12%; September - 21%).

However, at the same time, it should be stressed that a number of undertaken measures against traffic offenders was gradually decreasing from a number of 150.000 measures imposed in June, to 72.000 in August, and then to 20.000 in September.

More severe penal politics and through a wide range of the preventive and promotive activities on the media resulted in the increase of the safety belts use from previous 24% to almost 80%, that resulted in a decrease of the number of injured persons for about 1000 during the first three months of the law implementation.

4. Recommendations not adopted

Following recommendations and experiences of some countries, first of all those of Sweden and Hungary, dealing with benefits of using the running lights during the daylight, regardless to the visibility and light conditions, the mandatory use of running lights has been built the Law . But, this provision was changed during the Parliament procedure in a way that it remained built in the Law but without established sanction for non-compliance with it. So, this obligation has become facultative and has a character of recommendation.

We believe that mandatory use of the running lights, regardless to the light conditions, is justified from the safety point of view (according to experiences of the above mentioned countries the use of the running lights decreases a number of accidents for 10%, but at the same time, we assume that this novelty, important to us, slightly surprised a great number of those who were to decide upon it. An argument that Croatia is a tourist country that visit many foreign tourists who are not obliged to use running lights in their own countries finally prevailed. At the same time, the proposer did not obviously have sufficiently founded arguments to explain usefulness of its use. The reason might also be that a mandatory use of the running lights has been in force only in several countries, that was not a sufficiently funded reason to bring an affirmative decision.

It was also suggested that the way of the traffic lights operation should provide for a mandatory blinking green light (three times) before the shift of the phase, in order to warn the drivers in time that the free passing through the crossroads is about to end. Such technical solutions are used in other European countries (. in Austria), and a substantial number of semaphores in our country are programmed and are operating in this way as well.

Although the Law defined such semaphore operations only facultative, we consider it should be made obligatory in order to achieve a unified operation of all traffic lights devices in the country. We believe that, by providing such semaphore operation, we could improve a quality and level of the traffic safety in approaching to and passing through the semaphored crossroads.

We are highly interested in opinions of this respective gathering about benefits of using of the running lights during the daylight, and also about obligatory blinking green light before the end of its phase. We would also like to know whether you think that we should insist upon such solutions.

5. Conclusions

Changes and amendments of the Law on the road traffic safety brought about coordination between certain legal norms that refer to the traffic regulations and the legal norms existing in a majority of the Western European countries, achieving uniformity and confirming the rule that the traffic development and solutions have no limit indeed.

By introduction of the penalty points system, we have changed the penal system. We established a more severe penal policy in order to directly influence and increase a level of discipline of all participants in the traffic.

In a continuous care for the traffic safety we are open to accept advise and suggestions, positive experiences and results obtained from researches of more developed countries, in order to make qualitative shifts in the road traffic safety.

Although a period of three months is too short to give more reliable conclusions, this changed and amended law directly reflected in the improved safety level, showed by a substantial decrease of the traffic accidents number and their consequences. It also resulted in a large increase of the traffic flows range.

It is obvious that the Law has not been definitely formulated yet and, in a case of finding out more qualitative solutions, there will be more changes in the years to come.

At the end of this presentation, we would appreciate if the respectable experts and scientists engaged in the road traffic field, would make their estimations and present a critical review of our attitudes and attempts that we undertake in creating of conditions necessary for the safe participation in the traffic.

We would also highly appreciate if you would, using your precious experience, show us the way we should take on; and also to indicate us the questions on which we should pay a special attention.

BEHAVIOR OF THE DRIVERS AT THE SEMAPHORED CROSSROADS WITH AND WITHOUT BLINKING GREEN LIGHTBEFORE IT TURNS INTO THE AMBER, Mladen Gledec

Police Aceny

Zagreb

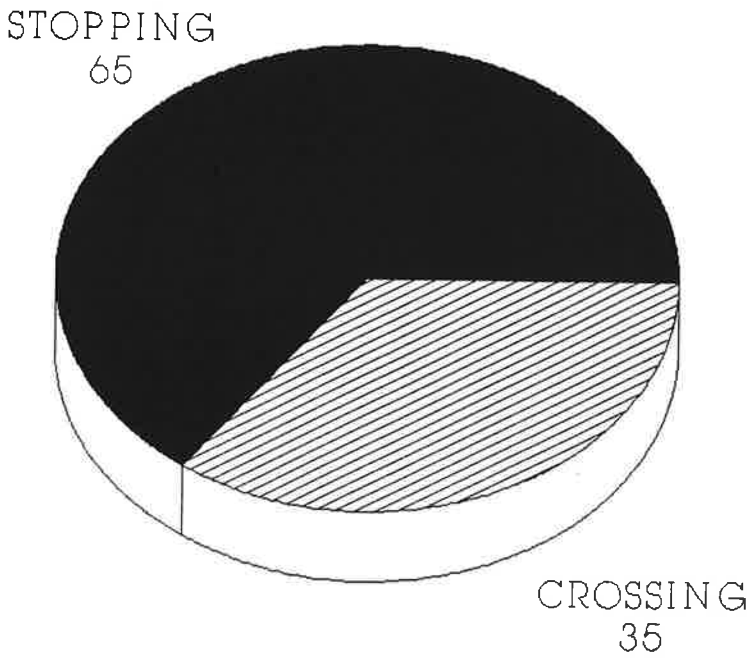
1. Ideal situation

An ideal situation when approaching the semaphored crossroads would be a division of the approach, when the amber turns on, into two zones:

- zone of passing, and
- zone of stopping.

A vehicle which, at the moment when the amber turns on, found itself in the zone of passage, will pass the crossroads, but the vehicle which is in that moment in the zone of stopping, will stop before the crossroads. In this ideal situation probability of stopping the vehicles when the amber turns on is a discrete function shown in the following Figure.

Figure 1: *Blinking Start (%), Becker (Israel Study)*



All vehicles that are, at the moment when the amber turns on, away from the crossroads more than a length “a”, will proceed driving on and will pass through the crossroads. Vehicles that are, in that moment away more than the length “a”, will start braking and will finally stop before the crossroads.

But, such an ideal situation cannot be realized because the drivers approach the crossroads with different speeds and the process of making a decision, like all other human characteristics, is not in its nature discrete and deterministic but rather continuing and probabilistic.

2. What could the situation be?

For example, the following chart demonstrates what could be the driver’s reaction when the amber turns on.

Every curve in this Figure presents a function of probability to make a decision to stop a vehicle, for a specific approaching speed, at various distances from the stop-lines. Thus, a mixture of interrelations between decisions to stop a vehicle and those to pass through the crossroads can be established for each separate distance. A point which the drivers find the most difficult to make a decision at, and therefore the point that shows a high rate of disparity in their choices, is the point at which 50% of drivers make decision to stop the vehicle, and 50% of them make a decision to pass through the crossroads.

The area that runs from the point at which 10% of drivers stop to the point at which 90% of drivers stop, is usually defined as a ZONE OF INDECISION.

When the problem of the zone of indecision is considered from the traffic-engineering point of view, then the primary interest is focused on the speed of a vehicle when approaching the crossroads, that is, on the length of its stoppable way.

This Figure shows a curve of the stopping distance of a vehicle as a function of the speed (without the way of reacting, with a minimal coefficient of friction which is 0,18).

Beside the curve of the stoppable way, this Figure shows the distances passed by a vehicle during the amber, that lasts 3, or 6 seconds. All three curves together define two different zones in approaching the crossroads:

- zone of dilemma (choice between two fires), and
- zone of option.

In the zone of dilemma, (which, in this Figure, exists only in a case when the amber lasts 3 seconds), a driver is faced with a choice between two unpleasant possibilities:

1. to apply severely the brakes, risking to stop the vehicle behind the stop-line at the crossroads, or
2. to continue driving (with an increased speed), risking to pass the stop-line through the red traffic light.

In the first case, the risk to cause a rear-end collision is larger than the risk in the second case to cause the side collision of the vehicles. The safety and the formal-legal problems of the "dilemma zone" could be solved by a prolonged duration of the amber, for more than usual 3 seconds.

3. *What is the situation?*

How does it look like in practice? For example, at the crossroads in populated areas, where the speed limit is 50 km/h?

If the approaching speed to the crossroads is not higher than 50 km/h, and if an appropriate magnitude of slowing down (namely, the friction) that could be realized at the stopping action, and on wet, and especially, on dry pavement, is 3 $m/s^{2\text{(on a square second)}}$, in that case, when the amber turns on - in duration of 3 seconds - all vehicles which at that moment were more than 30 to 35 meters away from the crossroads, should start braking and stop before the crossroads. However, those vehicles, which at that moment are closer to the crossroads than 30 m, should not decrease their speed, but should continue driving and should pass through the crossroads during the time the amber is on.

(For slower vehicles, this "critical" distance is, of course, smaller, while for faster vehicles, it is larger).

Above mentioned request of a legal nature, and in that aspect, is quite definite and clear-cut. Namely, the law on the traffic safety, where the role of the amber is defined, provides the following:

"when the amber autonomously turnes on, it means that a vehicle must not either cross the stopping line, nor enter the crossroads, if at the moment when the amber turns on, it approaches the traffic lights with such a speed that can guarantee the safe stopping."

As distinguished from this, it is less clear how the drivers should behave at the blinking green light, in those places at which the green light ends in this way. Namely, the legal provision defines the following: "The blinking green light serves to warn participants in traffic that the free passage is about to end and that the amber is about to turn on, that is, on the red traffic light", and it does not imply any specific form of the drivers behavior, except that, at such spots, a slightly reduced time of the drivers reaction when the amber turns on should be expected.

Based on legal definitions it must not be concluded that the blinking green light has the same role as the amber light has, because when the blinking green light turns on, the drivers are not legally obliged to stop their vehicle in front of the crossroads, unless they are, at that moment, at a distance which insures a safe stopping. If, under conditions similar to those previously mentioned - they drive with a speed of 50 km/h and a distance from the crossroads is at least 30 to 35 m - and during the time when the amber is on, that is, during the blinking green light of 3 seconds, if the driver would begin stopping his vehicle at the moment the green light begins blinking, then the vehicle would stop in front of the crossroads well during the duration of the amber - about 1,5 second before it would turn off.

The question is, to what degree the legal request is respected in practice, and to what extent, that is, whether the degree to which it is respected is influenced by the blinking green light, and how?

This question is not easy to answer. In order to answer it, it would be necessary, for each separate vehicle at the same time, to establish its speed and its distance from the crossroads, at the moment when the amber turns on; then, it would be necessary to establish the drivers reactions, in terms whether they changed or not the speed of their vehicle.

The only way to answer precisely and reliably this question should be through a thorough spacial-time analysis of movement of each vehicle, which is almost impossible to perform but through the computerized image processing techinque.

However, if we are looking for rather qualitative than quantitative nature, some more simple techniques can be used as well. For example, qualitative comparison on a sample of randomly chosen real traffic situations.

What is a common behavior of drivers at the crossroads at which the green light ends with BLINKING?

As it can be seen, when the green light starts blinking, virtually there is no any visible reaction of the drivers, and frequently they do not react even when the amber turns on, although it should not be so.

If this reaction to the amber is late, it is motivated by a "strong parallel sources of information", that could be a policeman standing in the area of the crossroads, perceived at the last moment, which can be rather dangerous in that case!

But, this is obviously a specific case, instructive in another sense, showing us that the "parallel strong sources of information" should never be set at the crossroads, especially not if they are partly covered.

In some cases, except the fact that reaction to the amber failed to take place, reaction to the red light fails to come, ... therefore the drivers enter the crossroads during the first, ... and even during the following second of the red light.

In rare situations the drivers react even on the green blinking light, but these are mainly the cargo vehicles drivers.

However, this can be very dangerous because it is unexpected.

Situation is slightly different at the crossroads at which the green light DOES NOT end with blinking.

In these situations, when the amber turns on, the drivers usually apply the brakes sharper, which could, factually, be a result of, not only absence of the blinking green light, but also, in some cases, a result of too short duration of the amber, in comparison to the approaching speed.

When the green light ends without blinking, it seems that diversity of the drivers behavior is more expressive, obviously as a result of present and expressed "zone of dilemma". When the amber turns on, a certain number of drivers that found themselves in the zone of dilemma, decide to apply brakes - mainly sharply, and the others continue driving or speeding up, entering the crossroads when the amber is about to end that is, at the beginning of the red light period.

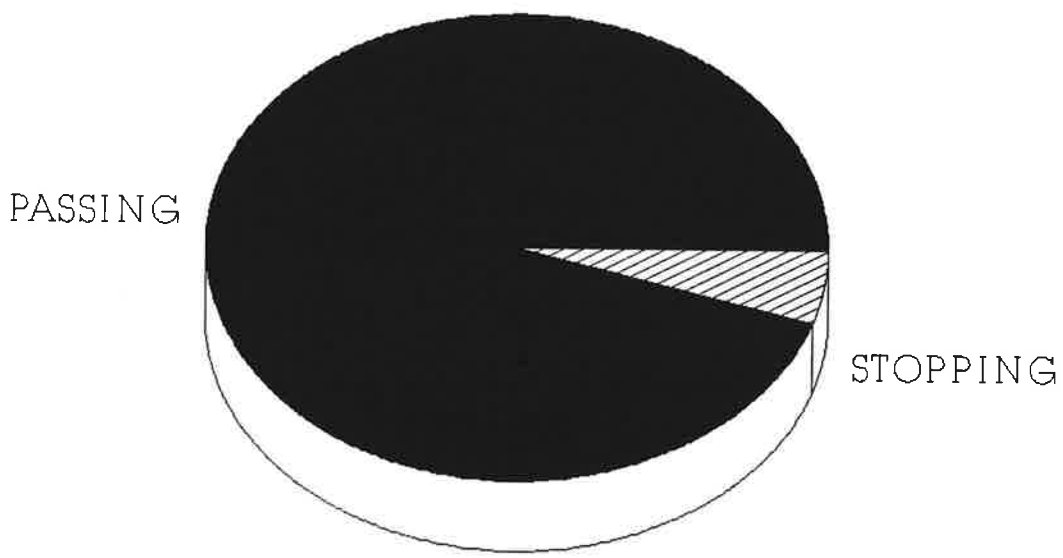
This, of course, can be very dangerous, although it appears that speeding up and passing through is less dangerous in such a situation, than a sharp braking.

4. Conclusion

Conclusion, imposed by the above presentation and comparisons, could be attributed to the following:

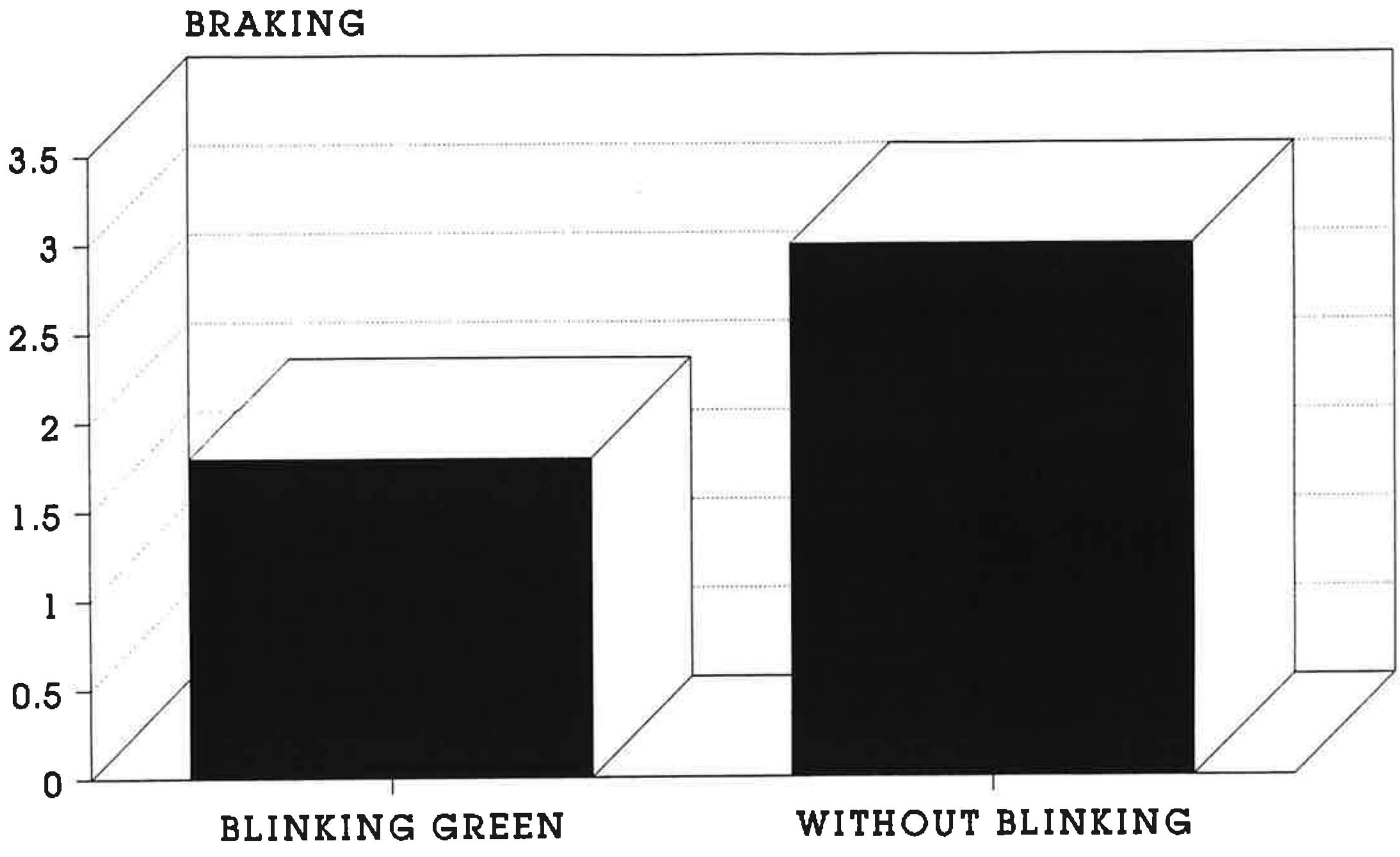
1. Appearance of the blinking green light at the end of the green phase almost does not have any influence on changes in the drivers behavior:

Figure 2: *Blinking Start (%), Estimate*



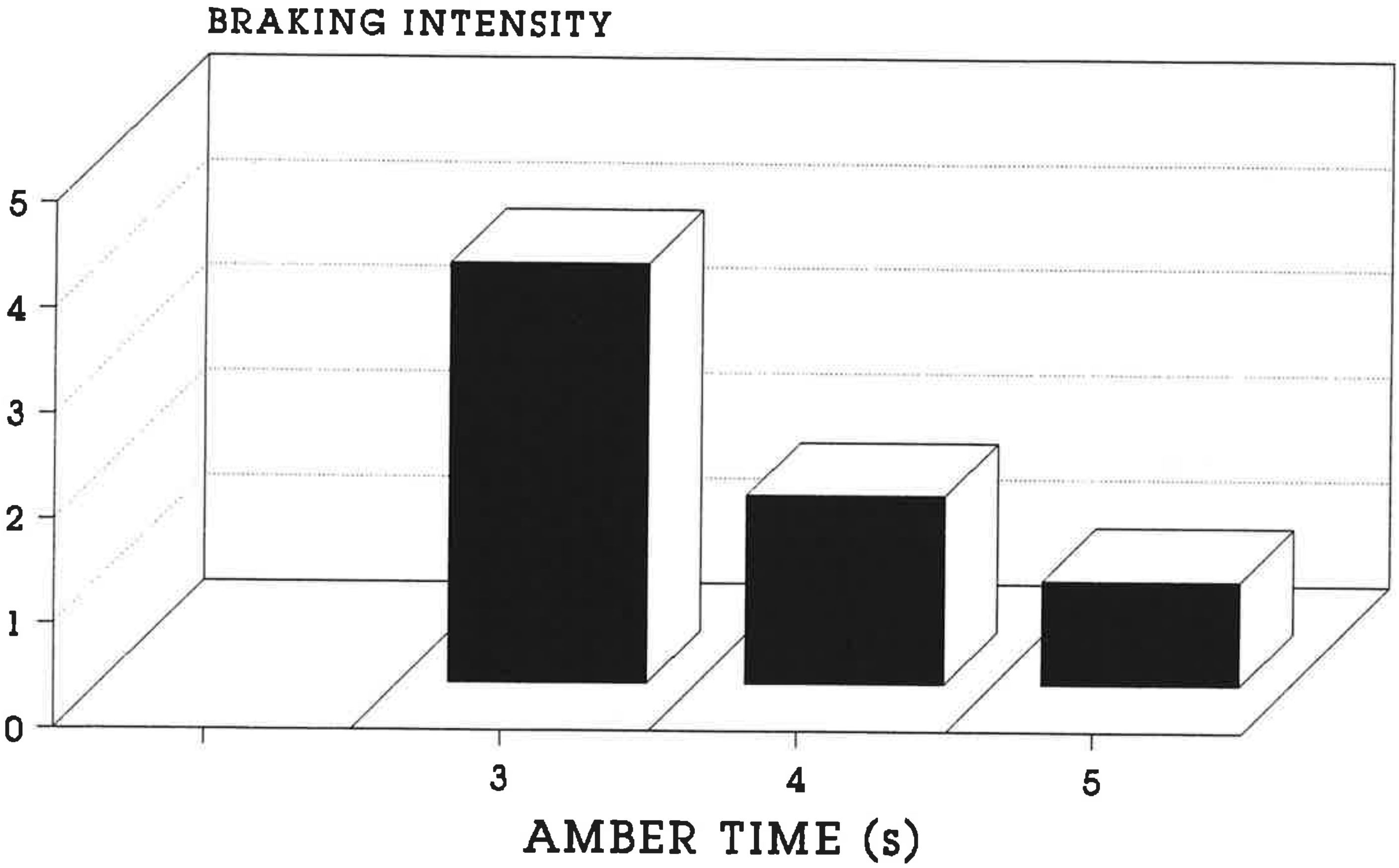
2. When the green traffic light, before it turns to the amber, ends WITHOUT blinking, stopping of vehicles is generally sharper - with more intense braking - than in the case when the green light ends WITH blinking. In other words, it could be asserted that a consequence of the blinking green light is more moderate stopping in front of the crossroads;

***Figure 3:** Braking Intensity at intersection, Estimate*



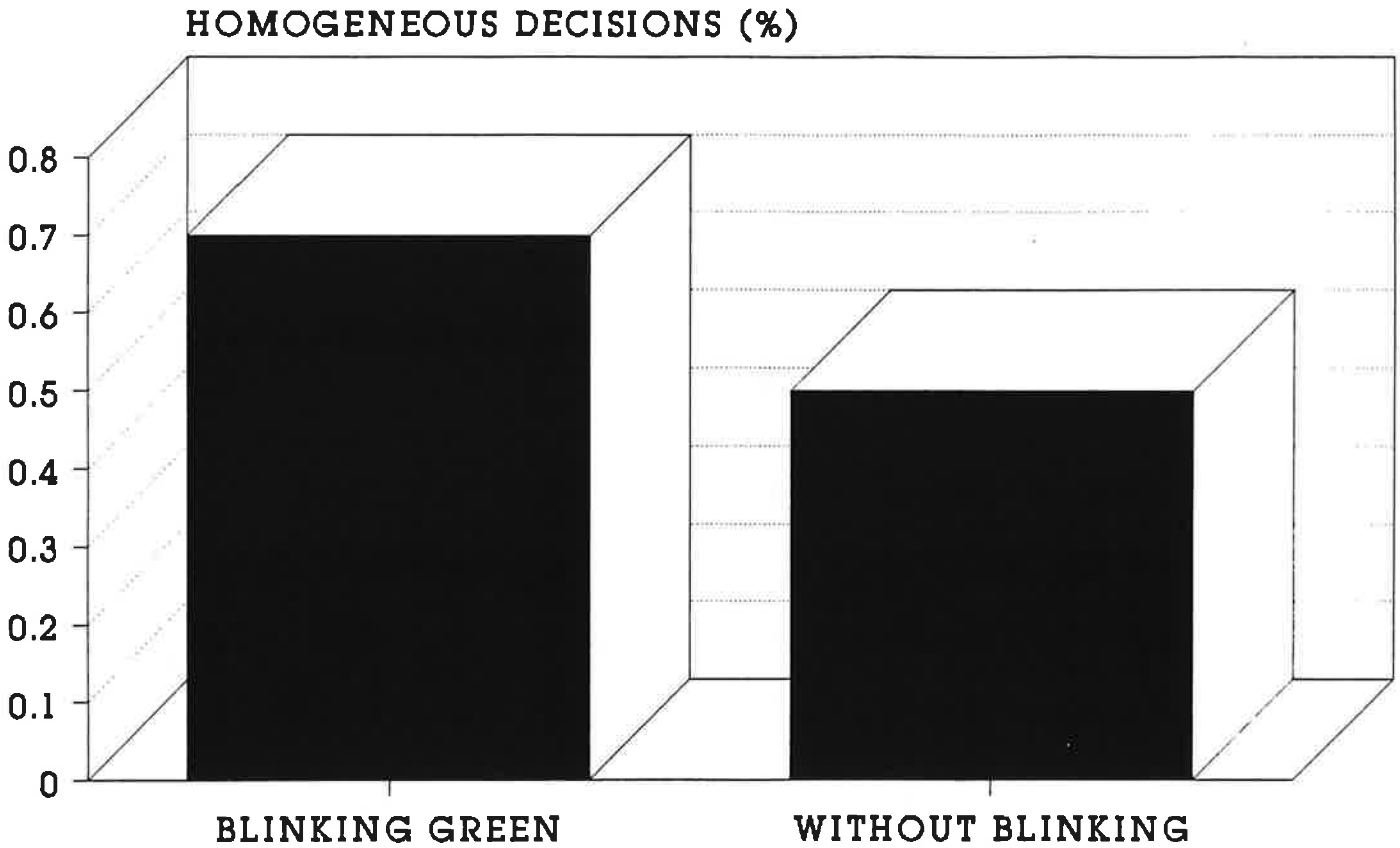
3. Duration of the amber influences the intensity of braking. When the amber, in relation to the approaching speeds of the vehicles, lasts shortly, that is, too shortly, then the intensity of braking becomes too high, which is not a good prerequisite for the traffic safety at the crossroads in any case.

Figure 4: *Amber time and braking intensity, Estimate*



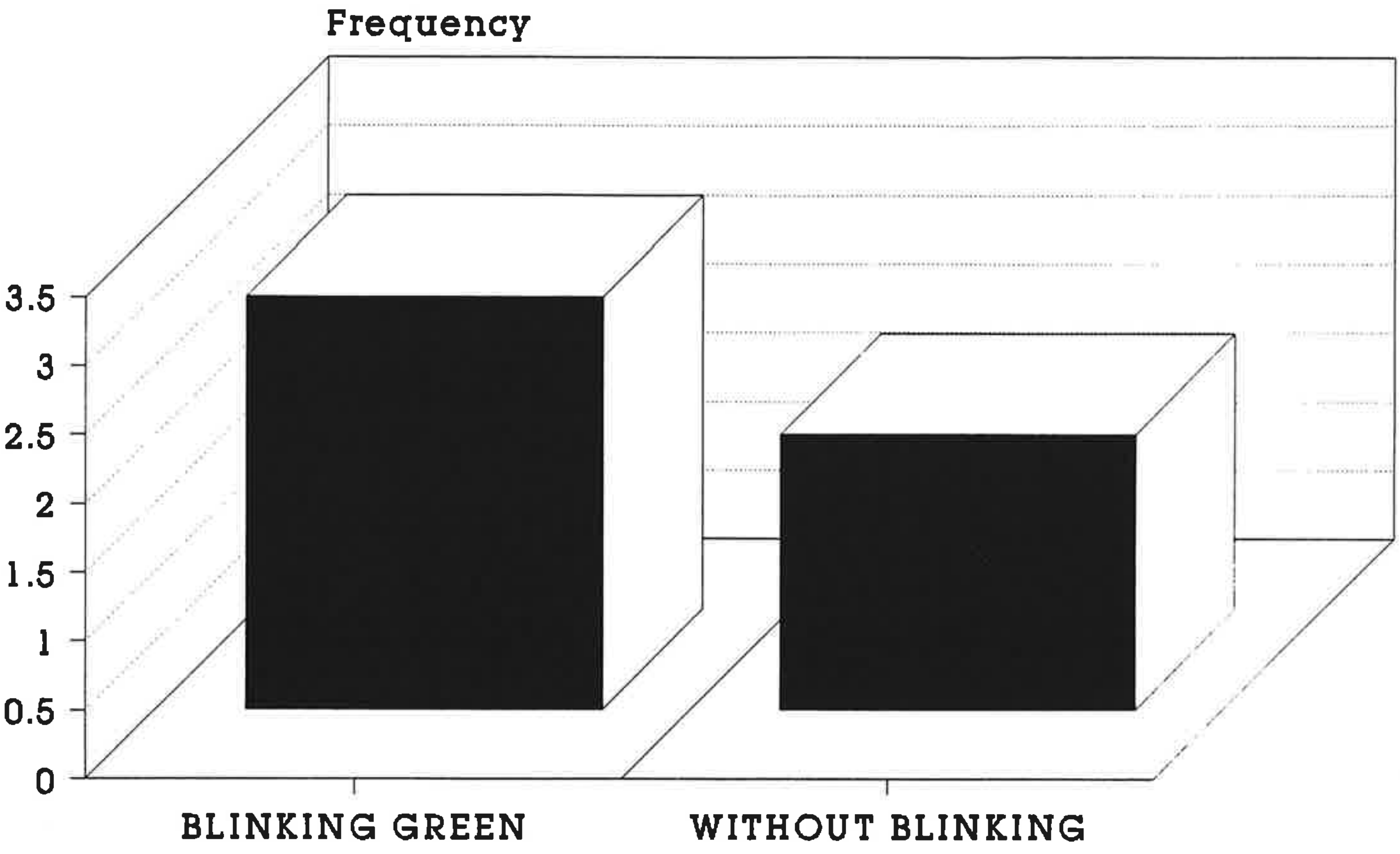
4. When the green traffic light, before it turns into the amber, ends WITHOUT blinking, it seems that non-homogeneity of the drivers reactions at the appearance of the amber is larger, that is, their behavior is more diverse. Namely, about 50% of the drivers, who at that moment found themselves in the "zone of dilemma", continue driving, and about 50% of them start braking.

Figure 5: *Decision homogeneity in „Indecision-Zone", Estimate*



5. When the green traffic light ends with blinking, it appears that drivers more frequently enter the crossroads on the red light.

Figure 6: *Green phase and crossing against red, Estimate*

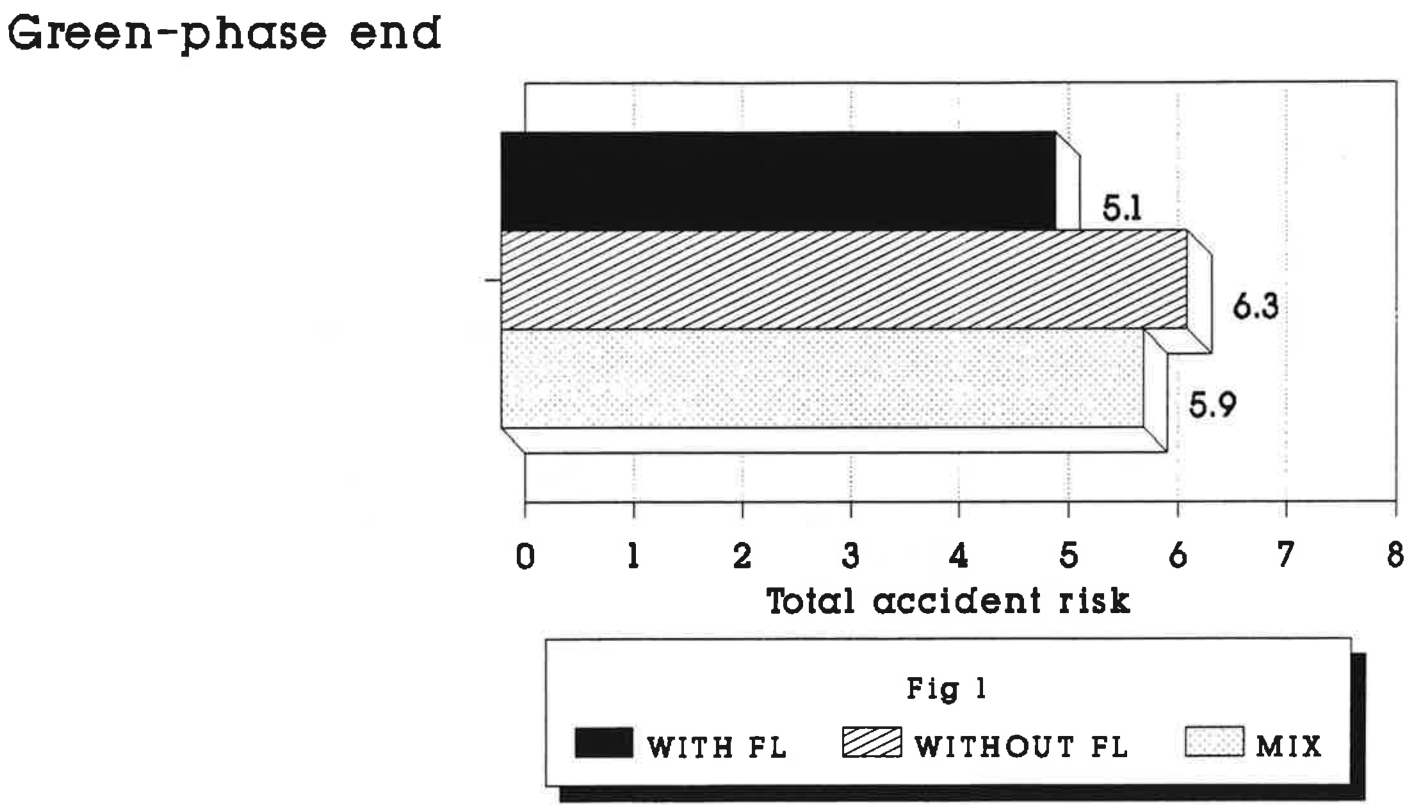


Could this conclusion contribute to the explanation and better understanding of recently obtained results from the statistic analysis of risks of the traffic accidents at the semaphored crossroads, with and without blinking green light before it turns into the amber?

Briefly, we obtained the following findings:

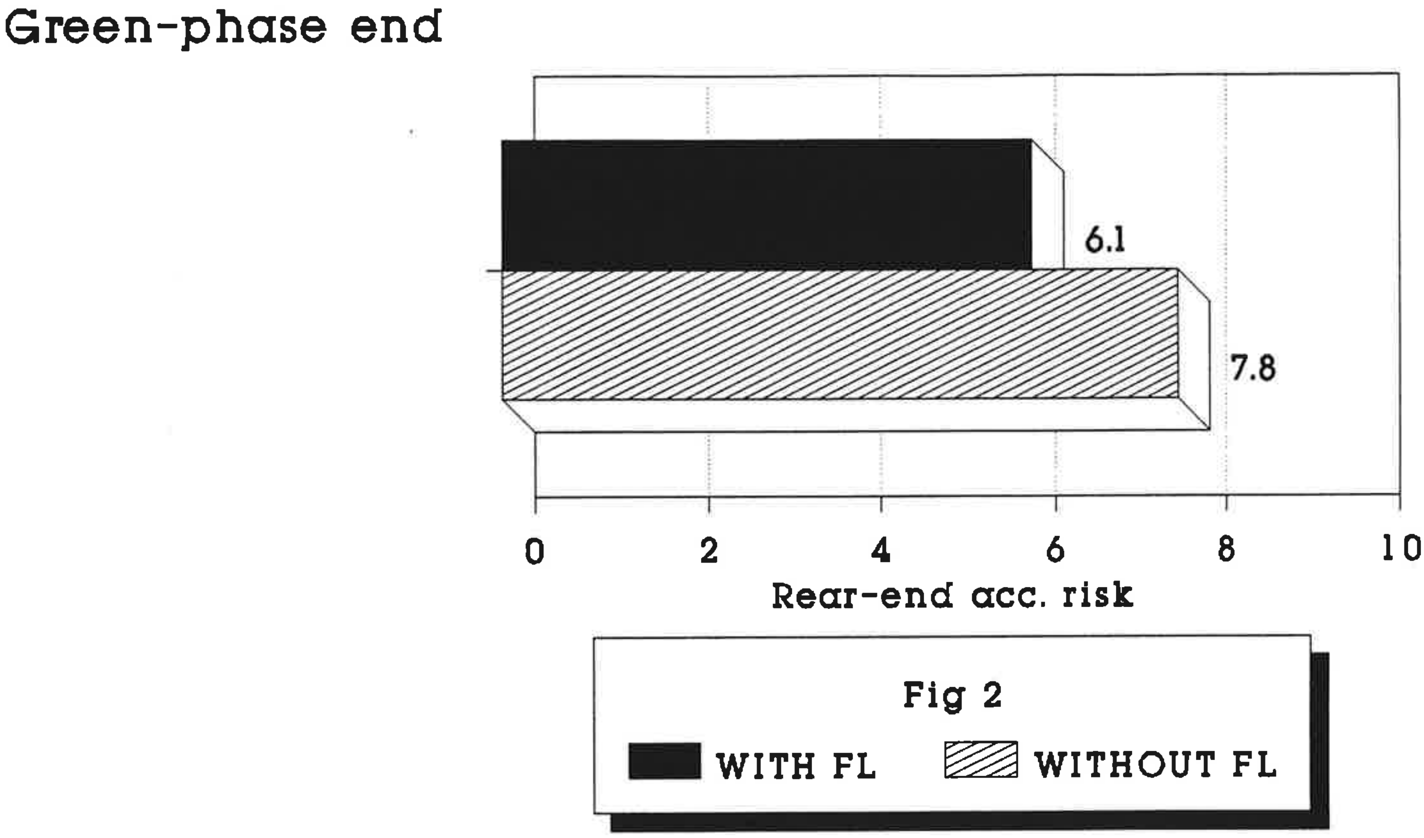
1. Blinking of the green traffic light influences a degree of the risk of the traffic accidents at the crossroads; When the green phase ends with blinking, the degree of the risk is LOWER, than when it ends without blinking and vice versa

***Figure** 7: Flashing Green influence on accident risk, Time Period: 1993-1995*



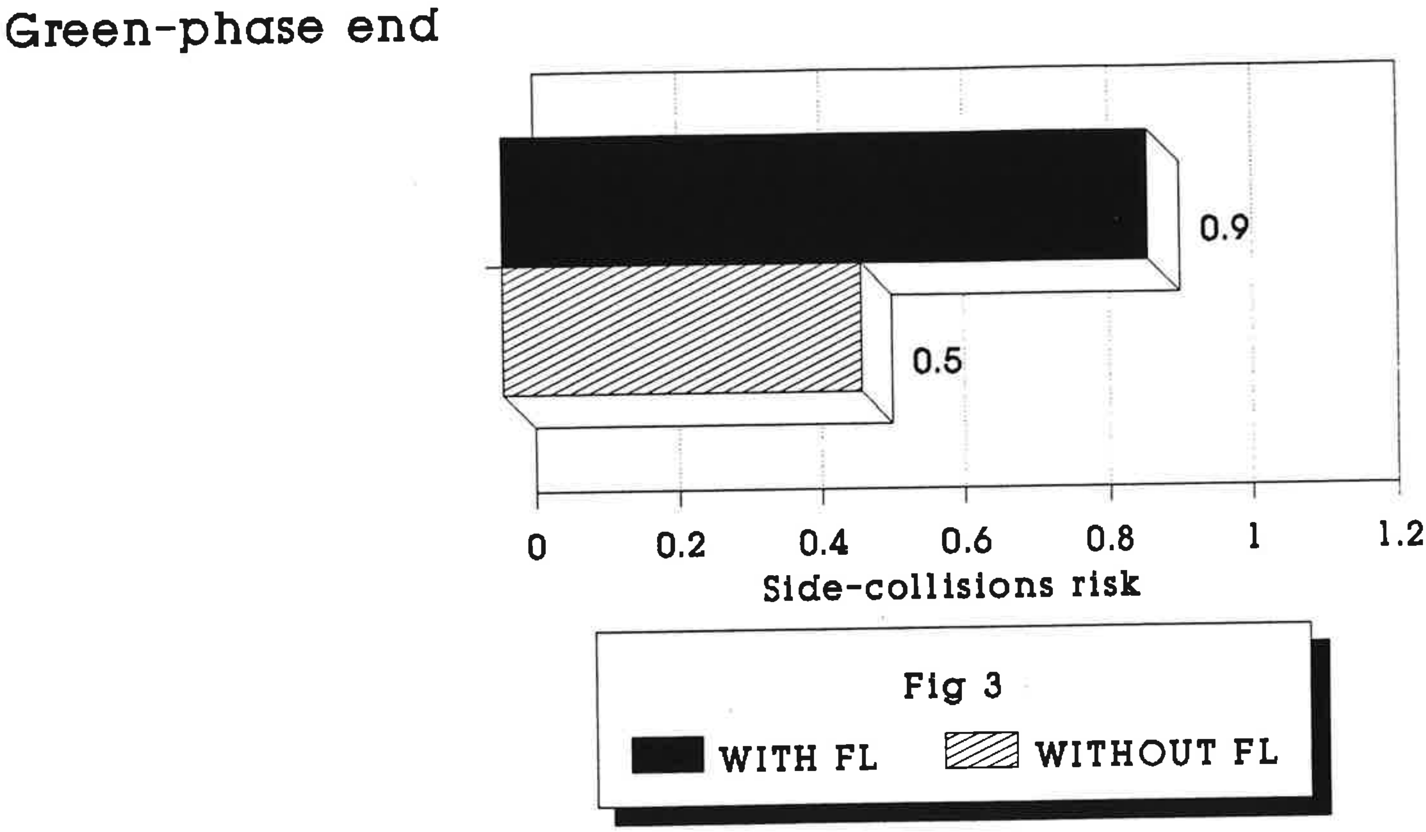
2. Blinking of the green traffic light significantly influences a degree of risk for the rear-end collisions accidents; When the green phase ends with blinking, the risk of the rear collisions is LOWER, than when it ends without any blinking;

Figure 8: *Flashing Green influence on rear-end collisions, Time Period: 1995*



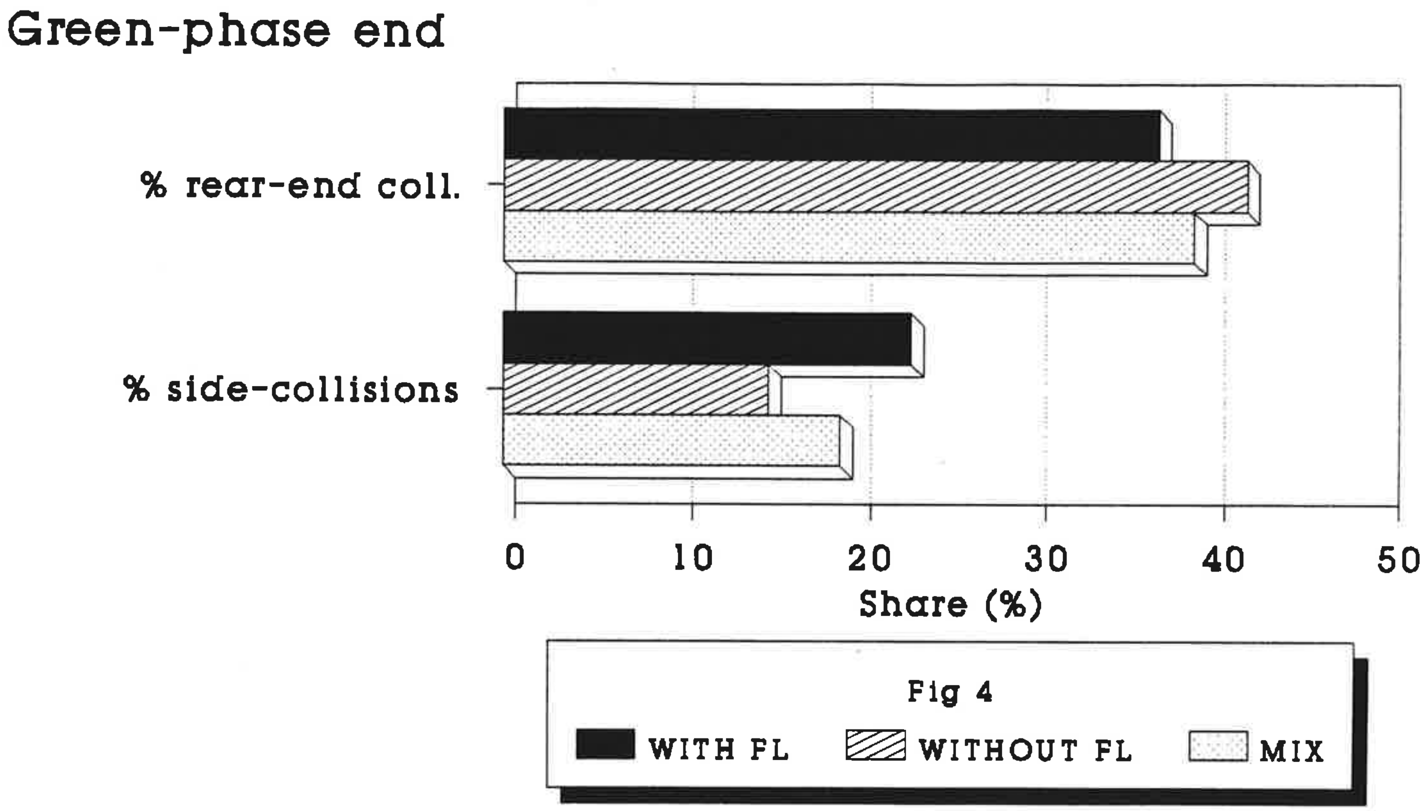
3. Blinking of the green traffic light does NOT significantly affect the degree of the side collisions risk at the crossroads, although there are certain tendencies which could be observed in that sense; Namely, in case when the green light ends with blinking, a proportion of the side collisions is LARGER than when it ends without any blinking;

Figure 9: *Flashing Green influence on side-collisions, Time Period: 1995*



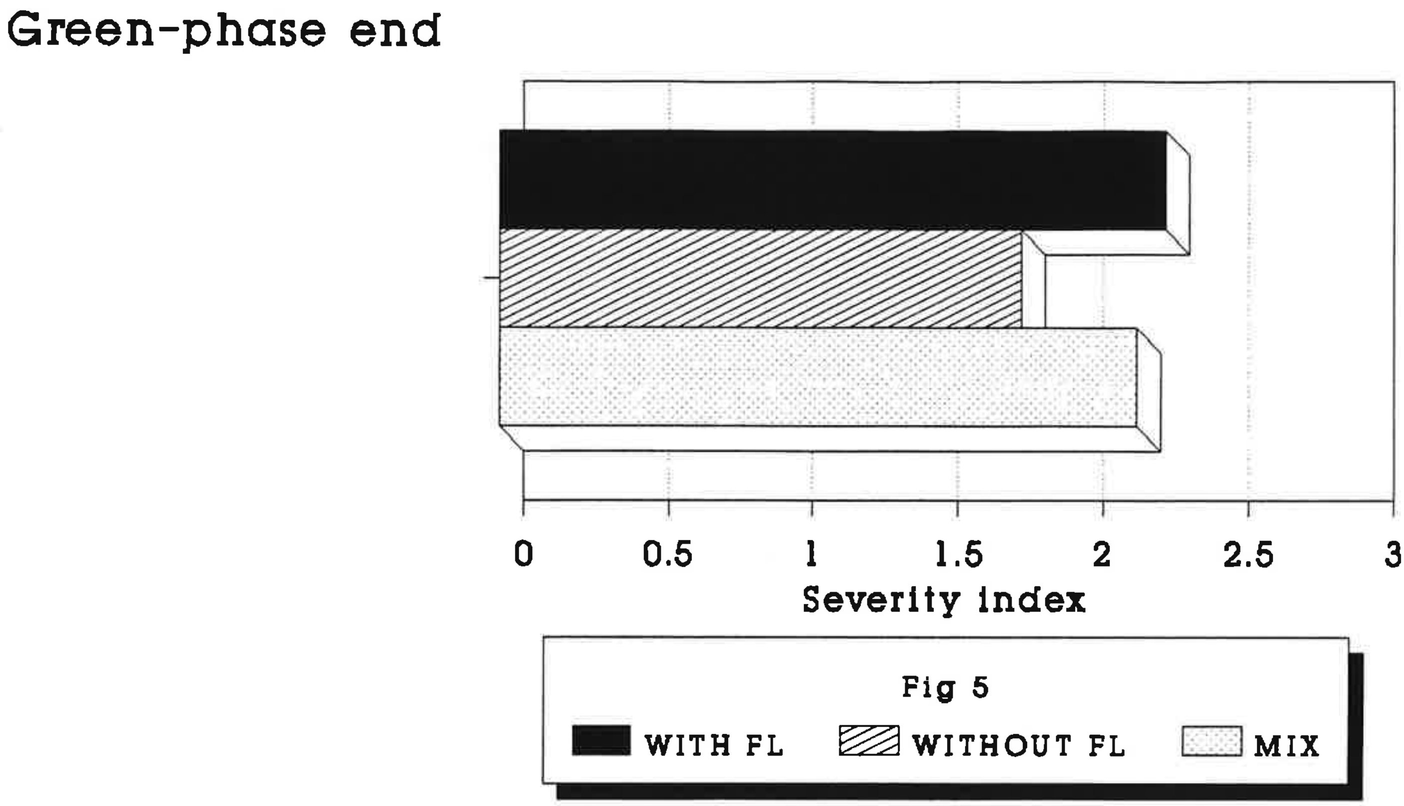
4. Blinking of the green traffic influences the structure of the traffic accidents at the crossroads in a specific way; In case the green phase ends in such a way, a share of the side collision accidents is HIGHER than in cases in which the green phase ends without any blinking;

Figure 10: *Flashing Green and accidents structure, Time Period: 1993-1995*



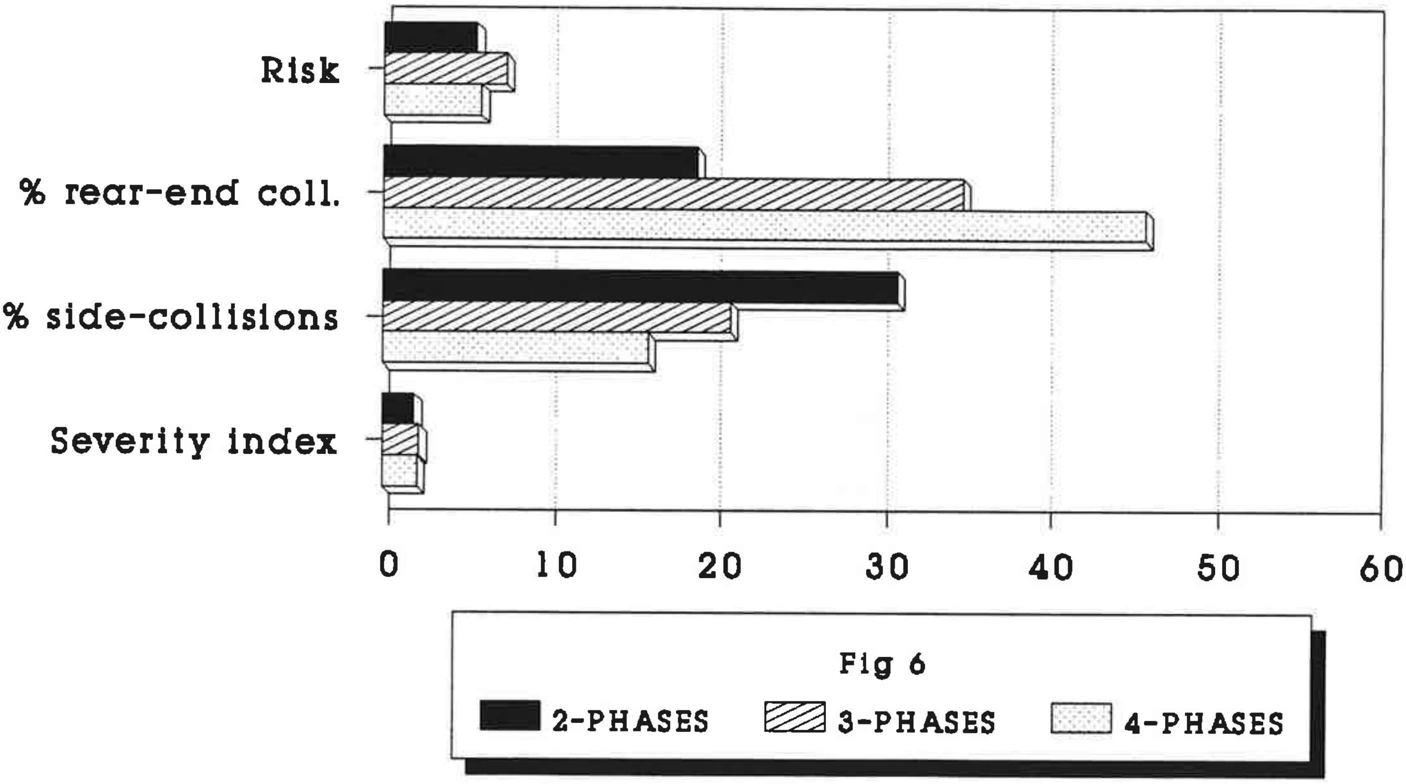
5. Blinking of the green traffic light INCREASES the factor of severity of the traffic accidents, that is, it results into more serious consequences of the accidents;

Figure 11: *Flashing Green influence on accidents' severity, Time Period: 1993-1995*



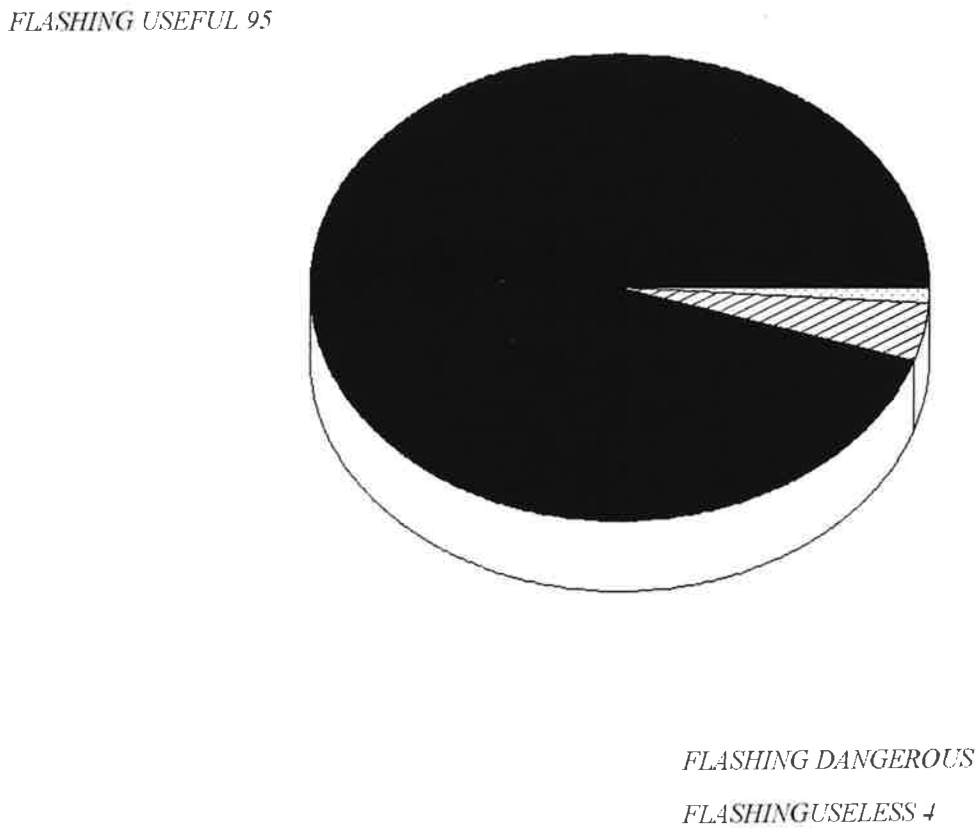
6. Number of phases within the traffic light cycle does NOT influence the degree of risk of accidents at the crossroads, but it AFFECTS their structure; The larger the number of phases is, the higher is the portion of the rear-end collisions in the total number of accidents, and the number of the side collisions is smaller, and vice versa; Number of phases within the cycle does NOT influence the factor of severity in the accidents;

Figure 12: *Signal Program (Phase), Time Period: 1993-1995*



Drivers mainly have a clear attitude toward the ending of the green traffic light, but in most cases their attitude is as follows: "In my opinion, the blinking of the green light at the end of the phase is useful and necessary, because it provides me more time to make a proper decision."

***Figure 13:** Drivers survey attitudes (%)*



When the findings obtained from previous analysis of risk, and the results obtained from the previous comparisons, are considered together, it appears that a role of the blinking green light could be briefly explained as follows:

- Blinking of the green light at the end of the phase, before it turns into the amber, results into more homogeneous way of reaction of the drivers to the amber, and also toward stopping of the vehicle with a lower intensity of braking, but it at the same time results into more frequent entering the crossroads on the red light.
- This way of behavior of the drivers in case of the blinking green light could explain a lower risk of accidents involving the rear-end collisions and an increased share of the side collisions accidents within the traffic accidents structure, that is, a higher factor of severity of the traffic accidents in such cases;
- When the green phase ends without blinking, it results into a larger variety of the drivers behavior toward the amber, toward more intense braking when stopping the vehicle; (which is higher if the approaching speeds are higher, and the duration of the amber is shorter).

This way of the drivers behavior when the green light ends without blinking could explain a higher risk of the rear-end collisions at these crossroads.

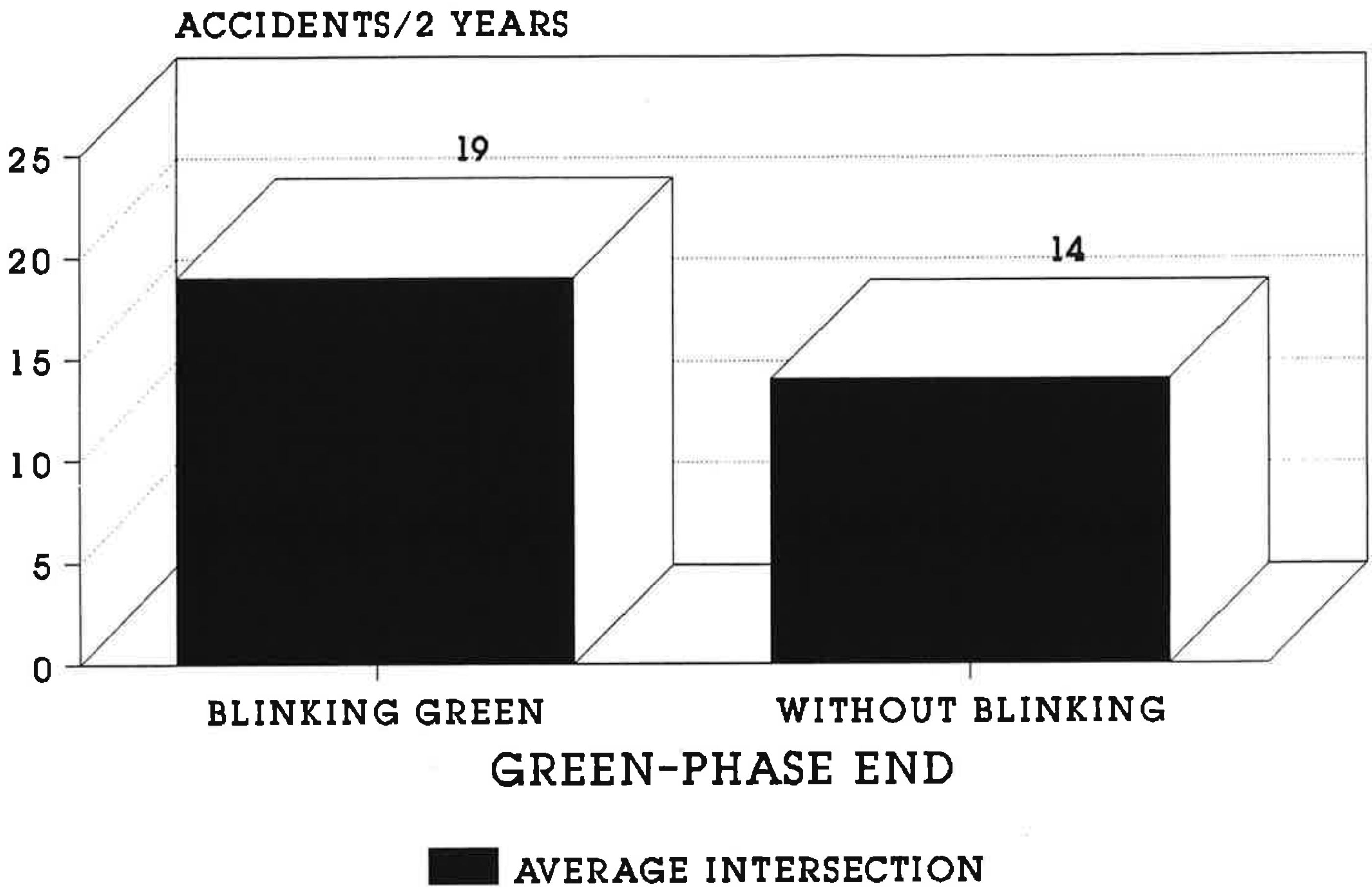
Some other, earlier and very famous researches, like those conducted by Israel, for example, obtained significantly different results.

The three-year traffic accidents analysis on a sample of 319 urban crossroads in Israel, found that a mean number of the rear-end collisions was higher at the crossroads equipped with the blinking green light, than at those equipped only with the amber. On the other side, they registered a slightly lower number of the side collisions at the crossroads equipped with the blinking green light. They found out in the conclusion that blinking of the green light increases a number of the rear-end collisions, and that virtually there were no other significant changes.

Significantly different results compared to ours, were obtained from the researches conducted by Becker (conducted also in Israel), which determined that 35% of the drivers, who found themselves in the zone of option at the moment when the green light starts blinking, make decision to pass through, and 65% of them make a decision to stop.

There is a possibility that some of these differences follows from different legal interpretations of certain terms, but also from different applications of the technical solutions as, for example, from different duration of the amber.

Figure 14: Israel Study, Hakkert, Mahalel



REFERENCES

GLEDEC M. (adopted 1986, revised 1992), Zagreb Master Plan

GLEDEC M., EVANS A. (1994), The Evaluation of Public Transport Safety Measures, Public Transport International, 3-1994, pp 32-35,

GLEDEC M. (1995), Zagreb Statistical Yearbook

GLEDEC M. (1995), The Police Bulletin on the traffic safety in City of Zagreb

GREEN MODES OF TRANSPORT AND TRAFFIC SAFETY - THE ZAGREB CASE, Stjepan Kelcec-Suhovec

City-Bureau-For Development

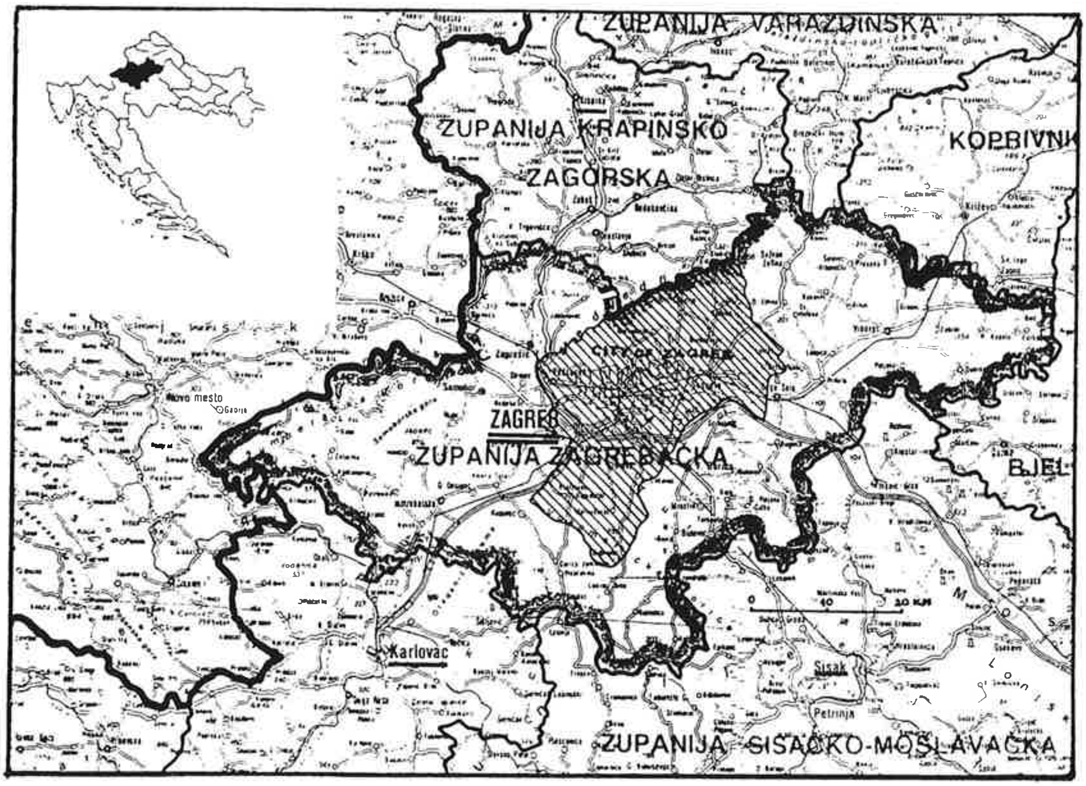
Zagreb

1. Introduction

1.1 Generally about Zagreb

Zagreb is the capital of Croatia with the population of approximately 800.000 inhabitants within administrative city borders /610 sq. km/. The Zagreb District comprises City of Zagreb plus surrounding towns and villages in and accounts approx. 1.100.000 inhabitants.

Figure 1: *CROATIA, Zagreb District, City of Zagreb*



There are in total 152.000 passenger cars and 177.000 motor vehicles in the city of Zagreb /statistical data from 1995/. The public transport is based on a network of tram and bus lines and one railway line. The tram network includes about 51 km of double tracks and 115 bus lines are 1 240 km long. Since 1991 existing railroad has been integrated into public transport and has shown good results.

Present tendency in transport is slightly increasing in number of the passenger cars and decreasing in the public transport use.

1.2 City-planning

Sustainable development in the city-planning has been the prevailing philosophy in European. In the area of transport it means insisting upon the use of the green modes of transport and on application of restraints in the car use. It means wider use of the public transport, walking on foot and cycling and lower quantity of the car traffic. This philosophy has been accepted in Zagreb, too.

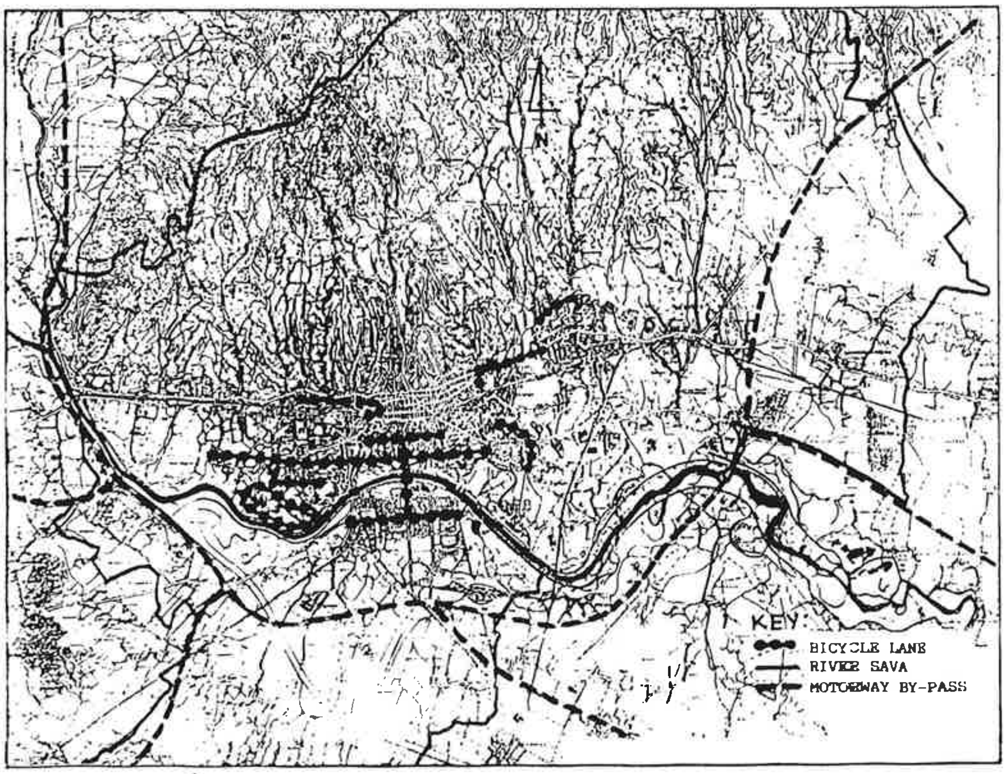
Among other useful results /lower energy consumption, lower level of air pollution, lower level of noise level, lower total costs .../ this philosophy is expected to **automatically result in a higher level of the traffic safety**.

Considering the public transport and restraints in the car use it should, without any doubt, contribute to improved traffic safety, but **we are suspicious about the role of the cycling in that process**. Could the cycling put things upside down?

2. Present situation with cycling in Zagreb

The cycling in the city of Zagreb cycling has been neglected for a long time. In the automobile age, that started in Zagreb in 1960s, the cycling was pushed out and the automobile oriented infrastructure was without a single bicycle way. The first serious steps in establishing the cycling network has been introduced only recently. It was mainly done by separating the pavements by yellow lines into pedestrian and cycling lanes. There are 34 km of streets with the bicycle lanes plus 7 km the bicycle lanes in the recreation zone of the Jarun Lake. These lanes are not connected among themselves, so the bicycling network for the moment is both, too short and inappropriately linked /fig 2/. The gaps in existing network are caused by a lack of adequate pavements that could be transformed into the bicycle lanes.

Figure 2: *Present bisycle network in Zagreb*



Lower City of Zagreb is very interesting area for cycling with a lot of destinations but it is strictly prohibited area for cyclists because of the safety reasons. Streets are occupied by the vehicles, parked cars and pedestrians and for the time being there is no surface that might be simply transformed into the cycling lanes. It seems necessary to do serious redesign of the street surfaces.

Existing data on the present participation of the cycling traffic within the daily town trips do not exist because there is no continuous monitoring of the situation in the traffic. According to our estimations the daily traveling by bikes is represented with a maximum of 1%-2% in total daily traveling during the dry and hot weather. The bicycle trips are rather based on leisure, and not for traveling from home to work.

3. The cycling in the Zagreb master city-plan

The Master city-plan is a basic document on long term development regarding the land use, infrastructure, transport and environment protection. It contains the goals and the basic strategic ways for achievement of the established goals. The City-Plan is developed in the graphic and textual forms.

In the area of transport, the goal is to provide safe and high quality of the transport system by insisting upon the use of the public transport and encouraging bicycling and walking. It automatically implies safety to come up by implementing this strategy plus reduction of the in motor vehicle traffic.

It has been officially anticipated that, by 2015, the number of the passenger cars will raise up to the level of 300 per 1.000 inhabitants.

Future transport network is presented in a graphic form at scale 1:10.000 and contains main roads, public transport routes and network of major cycling routes.

Cycling routes follow the main roads and the Sava River dams. The paragraph on cycling defines that the network would be completed according to circumstances.

The Plan does not contain a forecast of how important the role of cycling should exactly be in the future. According to our vision, daily travelings by bicycle might reach 10%-!5% in a total number of travelings, if an appropriate network would be built.

More detailed study on the transport has not been undertaken yet, there were only some general proposals for the cycling, that resulted in the present cycle network.

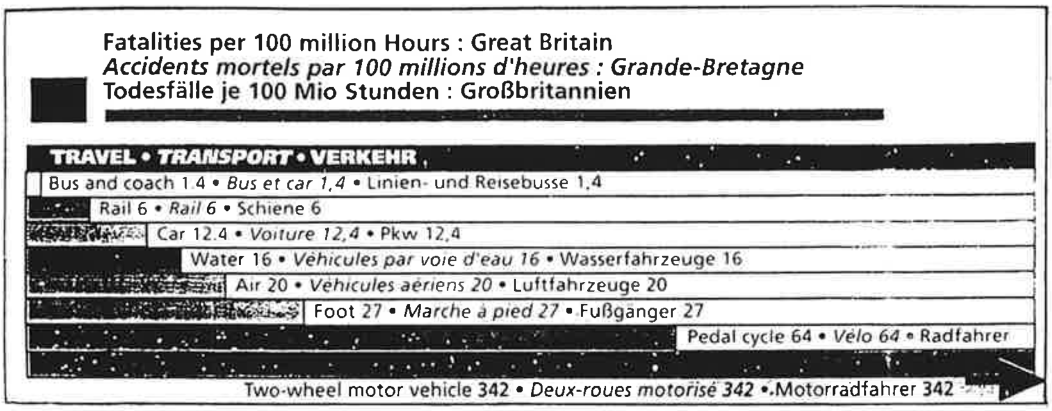
4. Road safety and what could go wrong related to cycling

There is an average of 800 killed people in road accidents every year in Croatia. Compared to the less than 5 million inhabitants and approx. 830.000 motor vehicles, it shows a high level of risk for people participating in the road transport.

According to the police report, in 1995 it was registered a number of 13.401 road accidents with 3.172 injured persons and 90 fatalities in the city of Zagreb The cyclists were represented in these accidents with 58 injured and 3 fatalities/77 accidents involving the cyclists/. Compared to the total number of injured people and fatalities it shows 1,8% injured and 3,3% fatalities.

The cycling is very risky way of transport. Expressed by fatalities per 100 million hours of traveling, the risk for cycling is 64, bus and coach traveling 1,4, rail 6 and car 12,4./Fig 3 according Ref. 2/ So, in our circumstances, as in a developing country with a low level of the traffic safety in general, I fear that a rapid increase in number of fatalities in cycling and the total number of killed people could reach a higher level even without the cycling.

Figure 3: The evaluation of transport safety



I believe in efficiency of a sustainable development and green modes of transport but I wonder if the road safety related to bicycling might be a weak point in this strategy.

The basic question is whether this fear is justified and real or I am too pessimistic? I would like to share my dilemmas with experts dealing with the road safety and, if this fear is real, what could be done in advance, besides the monitoring process?

<u>Note</u>: *The comment in this paper is not official attitude of the Institution where the author is employed*

REFERENCES

EVANS A. (1994), The Evaluation of Public Transport Safety Measures, Public Transport International, 3-1994, pp 32-35

The Police Bulletin on the traffic safety in City of Zabreb (1995)

Zagreb Master Plan, adopted 1986, revised 1992

Zabreb Statistical Yearbook 1995

DIFFERENT WAYS TO COMPARE TRAFFIC IN WESTERN AND EASTERN EUROPEAN COUNTRIES - A LITERATURE SCREENING FROM GERMANY AND A SHORT REFERENCE TO THE EUROPEAN PROJECT SARTRE, Ralf Risser

FACTUM

Wien

1. Introduction

In the following, some papers - mainly German ones, and one about a European project - will be listed and shortly presented where traffic in some Eastern and some Western European countries has been described. One paper about China is included, as well.

2. The SATRE project[1]

To start with, a short resumee of the European project SARTRE is given. SARTRE was a survey done in the EU-countries plus (at that time) Czechoslovakia and Hungary. It dealt with risk perception, views on speeding, attitudes to drinking and driving, seat belt wearing and reported driving habits among drivers of these countries.

In the following table 1, the average over all countries is given, and is compared to the results from Chekoslovakia and Hungary. Moreover, the data allow to introduce results from former Eastern and former Western Germany in the table.

2.1 Chekoslovakian Drivers

The table shows that Czekoslovakian drivers, compared to all drivers, retain very rarely

- that driving too fast may be the cause of an accident,
- that vehicles that can be driven very fast are one cause for existing safety problems,
- that they themselves are safer drivers than the others,
- that they drive with too short distance to the car in front,
- that they drive against amber light often,
- and that they overtake with very narrow margins.

[1] SARTRE 1994, Social Attitudes to Road Traffic Risk in Europe. European Drivers and Traffic Safety, Presses Ponts et Chaussées

At the same time, they report by far the highest involvement in accidents of all countries involved.

2.2 Former Eastern Germany

Drivers from former Eastern Germany, on the other hand, express their opinion very often

- that vehicles that can be driven very fast are one cause for existing safety problems,
- that the performance of the car is a very important aspect
- that they themselves drive safer that other drivers,
- and that restrictions of speeds on the vehicle side would be important

Very few interviewees from former East Germany answer

- that they often speed
- that they drive faster than the others
- that they enjoy taking risks
- and that they are in favour of higher speed limits

***Table 1:** Attitudes of drivers asked in the SATRE project (part 1)*

Questionnaire variable Selected countries	„Driving too fast" seen as cause of an accident	Vehicles capable of driving too fast are seen as the problem	Other drivers infringe the speed-limit rules	Self-reported speeding	Drive faster than the others	Enjoy driving fast	Enjoy taking risks	Performance of the car is considered important	Safer than other drivers
All	76,1%	56,2%	81,8%	19,4%	19,4%	36,6%	4,1%	34,2%	55,9%
Cz	*60,6*	*25,3*	80,0	16,9	17,0	41,6	6,9	43,0	*44,7*
De	**88,0**	**65,2**	86,3	*9,7*	*9,8*	42,6	*4,4*	**46,9**	**73,8**
Dw	78,7	64,0	*61,9*	12,1	12,1	**43,6**	5,5	36,8	58,9
H	71,1	55,8	**90,1**	**24,2**	**24,2**	*29,3*	**6,5**	*33,5*	59,7

Table 1: Attitudes of drivers asked in the SATRE project (part 2):

Questionnaire variable Selected countries	In favour of higher limits than 110 on rural roads	Restrictions of vehicle speeds on the vehicle side	Stated accident involvement last 3 years	Distance to vehicle in front often too short	Drives against amber traffic light often	Overtaking when one just can make it
All	6,44%	42,7%	0,112%	6%	16%	19%
Cz	6,35	31,8	***0,409***	*3*	*13*	*10*
De	*1,87*	**42,5**	0,070	4	15	11
Dw	**8,42**	31,9	0,171	6	21	26
H	4,6	*20,0*	*0,053*	**11**	**31**	**39**

Total sample: A, B, Cz, Dk, DE, DW, E, F, GB, H, I, Irl, Nl, P, S, CH

2.3 Hungarian Drivers

Drivers from Hungary retain more often than drivers from other countries

- that many drivers infringe the speed limit rules
- that they themselves speed very often
- that they themselves drive faster than the others
- that they enjoy taking risks
- that speeds to vehicles in front often are too short
- that they often drive against amber traffic light
- and that they overtake when they just can make it

At the same time, drivers from Hungary say more rarely than many interviewed drivers from other European countries

- that they enjoy driving fast
- that the performance of the car is important
- and that there should be restrictions of vehicle speeds on the vehicle side.

Hungarian drivers report the lowest degree of accident involvement of all interviewed nations.

2.4 Drivers from former West Germany

Drivers from former West Germany are in general average with respect to their answer frequencies. Only in two cases are they „best“: They state very often

- that they enjoy driving fast
- and that they are in favour of higher speed limits than 110 on rural roads.

At the same time, drivers from former West Germany express least often the opinion that other drivers infringe the speed limit rules.

2.5 Conclusion

These results can either be a basis for measures on the communicative level (campaigns) if no other data are available. However, much interpretation work is needed.

Or it can be the starting point for the definition of further research work, that makes use of, e.g., methods that are mentioned in the following.

3. Speeds in the „new countries“

The next summarised paper is the one of Lipphard in the Zeitschrift für Verkehrssicherheit (ZVS), the German „Journal of Traffic Safety“[2]. He refers to the „new countries“, as the federal countries of former Eastern Germany are often called in Germany, precisely as the federal countries of former Western Germany are often called the „old countries“.

3.1 Introduction

The speed behaviour of 285000 cars in former Eastern Germany has been analysed. The short-comings are that the analysis results are in some cases compared to nothing - neither in a before-after scheme, nor to other reference groups.

3.2 General neglection of speed limits

In total speed limits are neglected by more than half of the car drivers. 20% of the car drivers drive too fast on rural roads. At entrances into villages 90% drive faster than 50km/h, 30% drive faster than 70km/h. In town or village centers 1/3 drive faster than 60km/h, and a part of them faster than 70km/h.

[2] Lipphard D. 1994, Geschwindigkeiten in den neuen Bundesländern - Verhaltensänderungen 1991-1993. Neue Fahrbahnen, Ausstattung, Umfeld, ZVS 40, 4/IV

Table 2: % of cars and Lorries faster than 50km/h

Site	Cars faster than 50km/h	Lorries faster than 50km/h
town and village centers	45%	33%
entrances	87%	78%

3.3 Speed changes cfter surface reparations

Speed problems have arisen where the surface was changed, but where no work on the design was done.

Table 3: V85 before and after surface improvements

V85 of free cars on	before surface improvements	after surface improvements
Towns and cities	62	68
Rural roads	90	100

Speed went up drastically on streets with new surface (in average 15km/h in some samples).

On wet surface and under rain conditions speeds went in average up by 4km/h compared to dry surface.

On roads without repared surface from 1991 to 1993 speeds were reduced by 1 to 2km/h per year.

3.4 Other results

In East Germany there were general 80km/h on rural roads before the unification. Now it is 100km/h. On the remaining 80km/h pieces where signs have been put up speeds went down by 3-4km/h in average.

Mobile enforcement proved to be effective: In villages with mobile enforcement speed was reduced by 8km/h in average.

Alleys and parks roads go through do not reduce speeds. The figure shows that actually speeds on alleys are higher than on roads without trees near the road margin.

Picture 1: *V85 on alleys and parks roads go through*

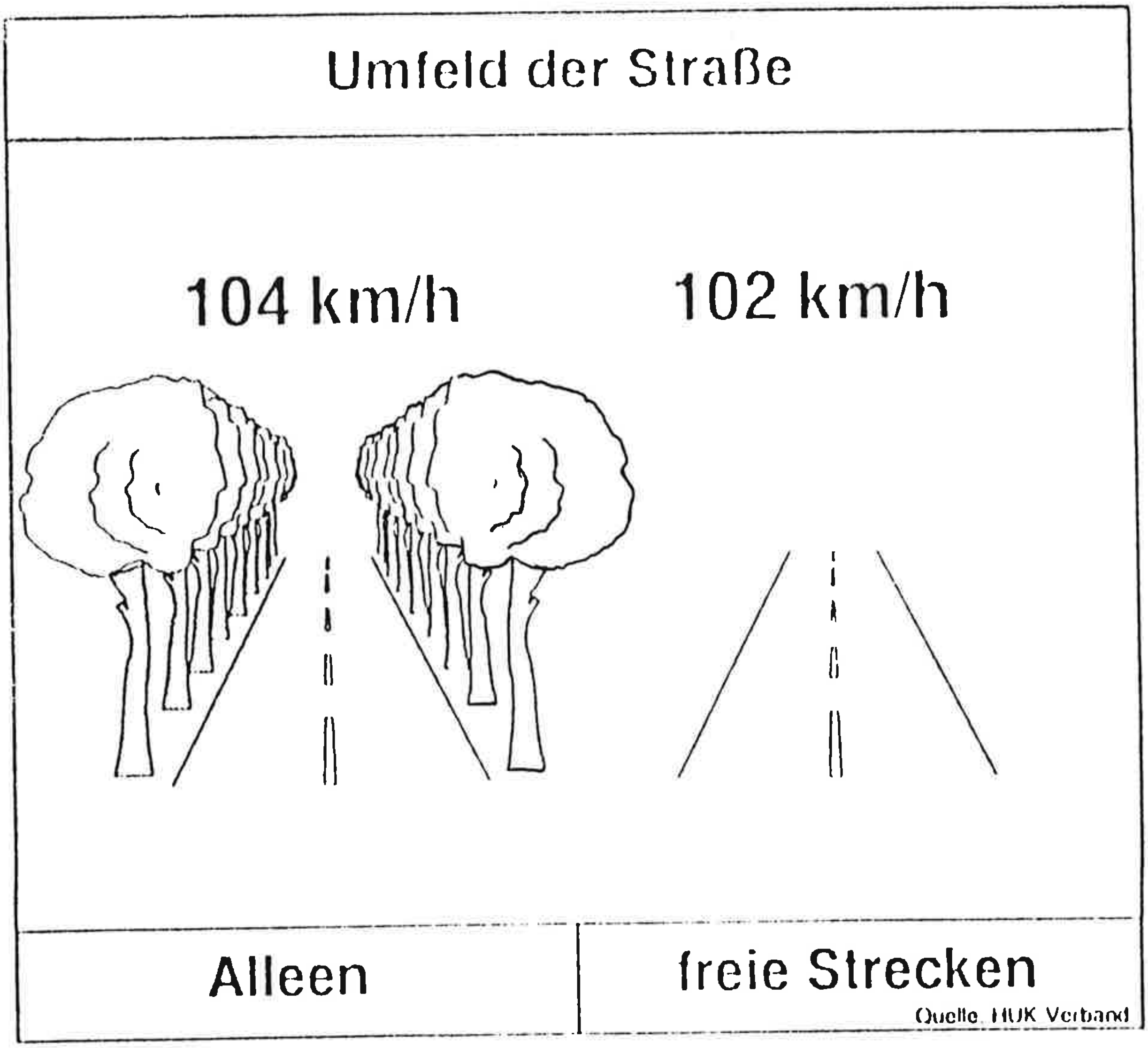


Bild 3: V85-Geschwindigkeiten von frei-fahrenden Pkw nach Straßenumfeld.

Males drive much faster than females, in villages 5km/h, on roral roads 10km/h. People in Western cars drive in average 10km/h faster than people in Eastern cars. At the same time, the portion of Western cars has been steadily rising:

Table 4: *Portion of Western cars 1991-1993*

Portion of Western cars	
1991	60%
1992	70%
1993	80%

However, there is no speed difference in towns or villages between Eastern and Western car makes.

Speeds by night are higher than daytime speeds:

Table 5: *V85 by night and daytime*

V85	
day	107
night	112

3.5 Conclusion

The results of the paper are interesting but of no great use if they are not compered to reference samples. Certainly, there exist, e.g., results from Western countries that can be compared to Lipphard´s data. But actually, the author should himself have referred to these to some degree.

4. Life style analyses in the old and new countries[3]

Young drivers do not represent a uniform group. There are very different groupings which differ from one another in several characteristics. Life-style and leisure-time characteristics, attitudes and driving behaviour differ very much and at the same time show clear relationships to accident involvement.

[3] Schulze H. 1996, Lebensstil und Verkehrsverhalten junger Fahrer und Fahrerinnen, Berichte der Bundesanstalt für Straßenwesen (BASt), Heft 56

4.1 Life-style and leisure time analysis

Life style analyses are based on surveys of attitudes and values that prevail among certain groups. They usually lead to a division of these groups into sub-groups. In the following, some graphs are shown that contain the values and attitudinal objects referred to in life-style and leisure time analyses.

Such analyses are, among others, relevant because they give a thorough basis for communication policy towards different target groups (i.e., information and education campaigns).

In the old federal countries, three types where identified - the **action**, the **fan**, and the **contra-type** - which turned out to be High risk groups with extensive exposure and a higher accident involvement than other groups.

Graph 1: Cluster of „Action-Type"

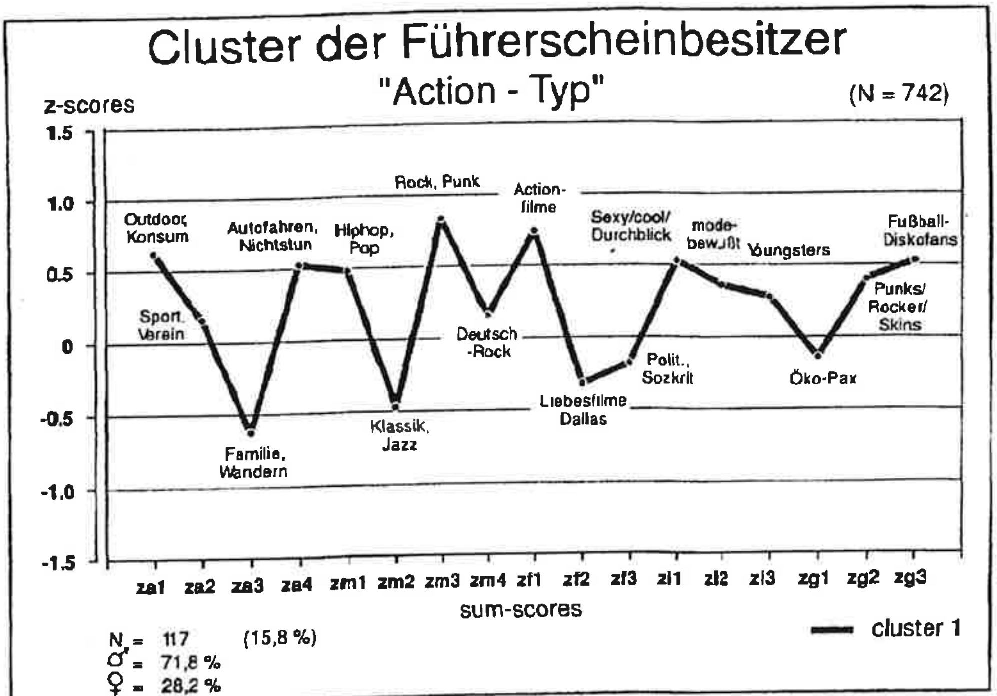


Abb. 4: Cluster der Führerscheinbesitzer „Action-Typ"

Graph 2: Cluster of „Fan-Type“

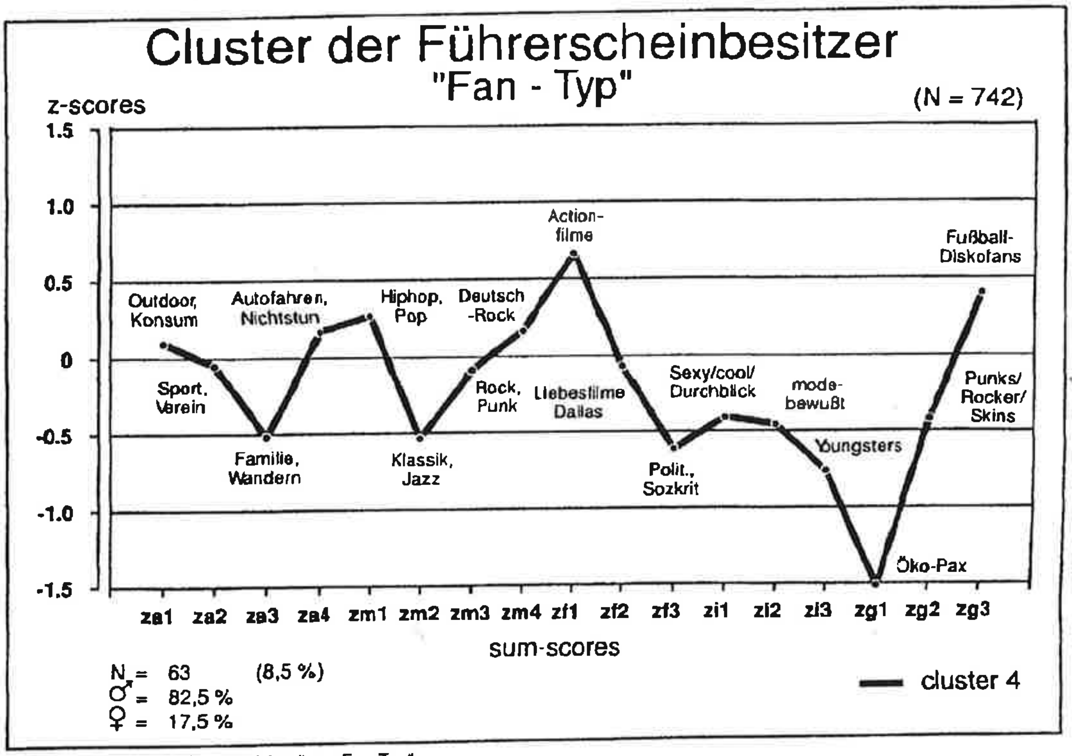
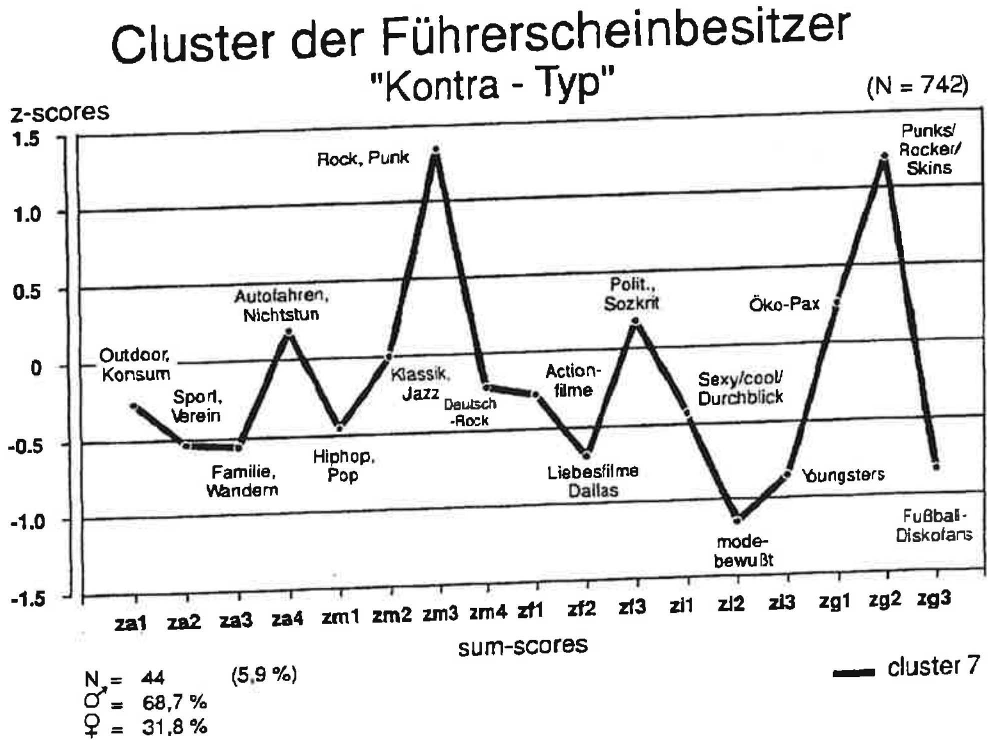


Abb. 5: Cluster der Führerscheinbesitzer „Fan-Typ“

Graph 3: Cluster of „Kontra-Type“

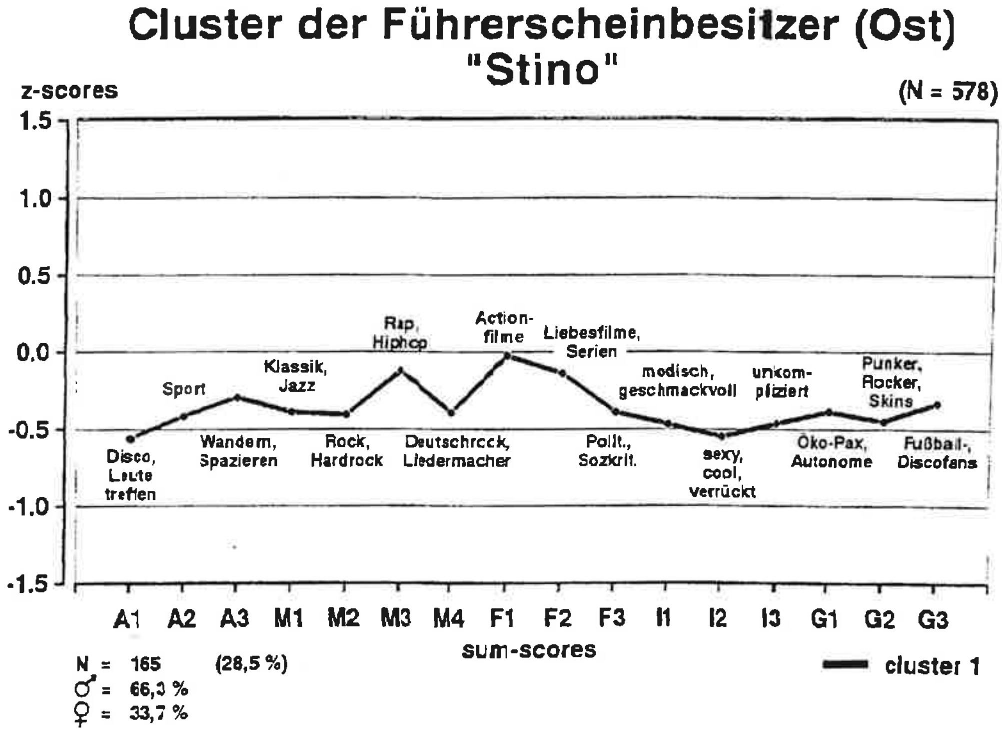


The following graphs show what values and what attitudinal objects are included in the life- and leisure style surveys:

These three problematic groups represent appr. 20 to 30% of all young drivers in the Western federal countries of Germany.

In the Eastern federal countries, the three most problematic groups are the „Stino“ (very negative type), the „Dreher“ (extroverted) and the „Easy rider“ type (masculine hedonistic type.

Graph 4: Cluster of „Stino“



Both the problematic groups in the Eastern and Western federal countries are also difficult to be addressed. In the Eastern countries it seems even more difficult as there are virtually no high loads on any positive values. At the same time, the problematic groups in the Eastern federal countries represent around 60% of the young drivers:

Graph 5: Cluster of Dreher"

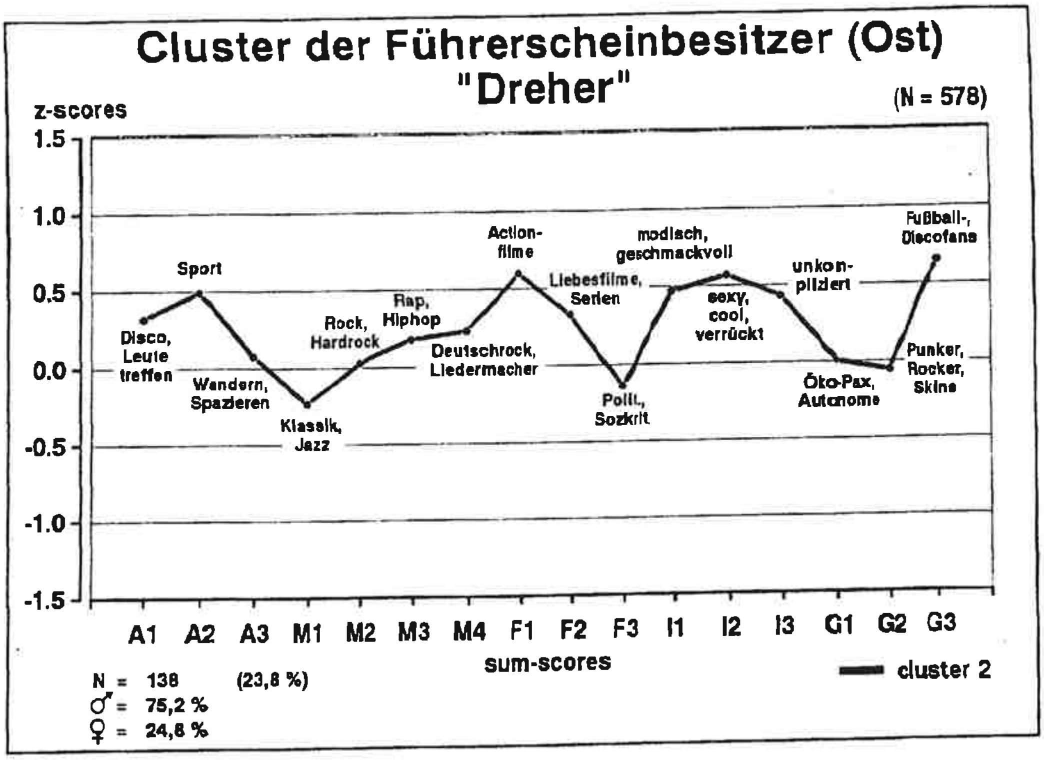


Abb. 17: Cluster der Führerscheinbesitzer (Ost) „Dreher"

Graph 6: *Cluster of „Easy Rider"*

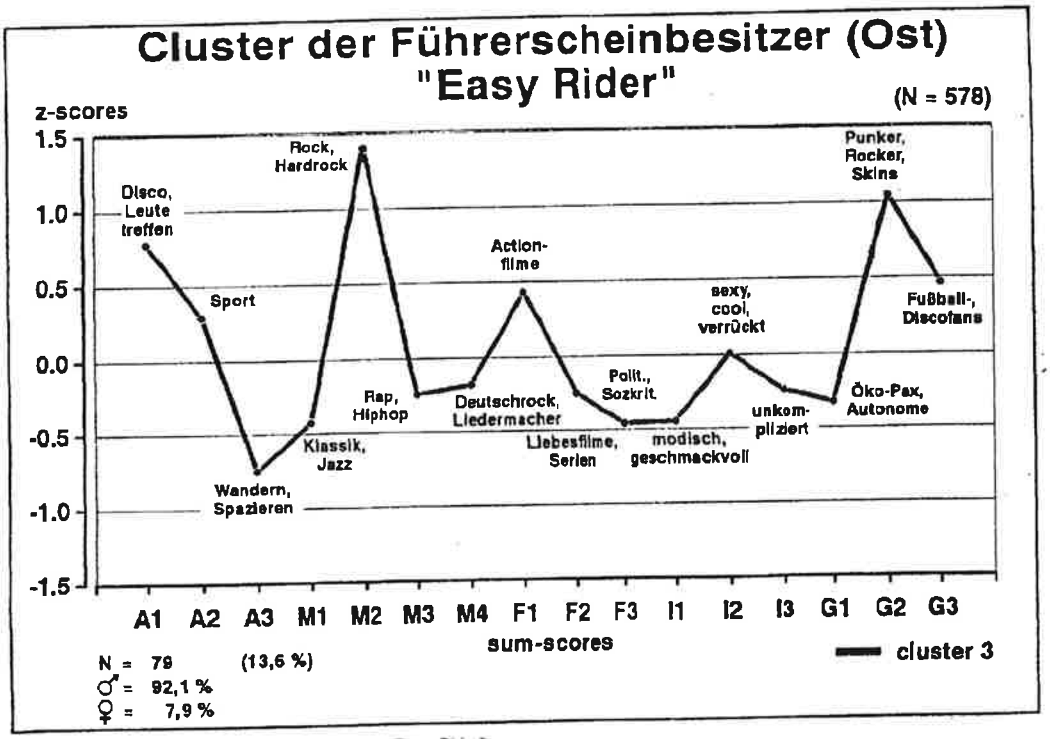


Table 6: *Percentage of problematic groups*

Western Federal countries	Eastern federal countries
Problematic groups: Fan-, Action-, and Contra.type 20 to 30%	Problematic groups: Stino-, Dreher-, and Easy-rider-type appr. 60% (28, 24 and 14)

5. Test drives in Germany

Test drives were organised by Reker[4] et al. near Berlin, 1991 and 1992. The main variables that were checked were speeds and changes in speeds on test routes by three groups: Persons from the old federal countries (A), people from the new federal countries (N), and prople from the new federal countries with a new car of Western make (U)

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[4] Reker K., Buss E. & Zwielich F. 1993, Fahrverhaltensbeobachtung im Raum Berlin, Berichte der Bundesanstalt für Straßenwesen

Table 7: Comparison between the three groups with respect to different variables:

	A	N	U
Accelerations and decelerations in inhabited areas		Slightly faster than the other groups	More than the other groups
Rural roads without housing		Significantly faster than A	Significantly faster than A
Motorways	As U, faster than N	Slower than A + U	As A, faster than N
Acceptance of time gaps at crossings		Accept shorter time gaps than A and N	
Interaction with vulnerable road users	Reduce speed continuously from 100 to 20 m	Do not reduce speed at all	Reduce speed continuously from 100 to 50 m
Norm orientation		Higher norm orientation than the other 2 groups	

Between the three groups there are no differences on urban main streets, and no differences on rural roads with housing.

Infrastructural elements (road surface characteristics, road paintings, etc.), do not differ in their effects on the three groups.

6. A comparison between PRC and Germany (old federal countries)

Very shortly, a paper by Liu[5] shall be summarised here that has been published in the ZVS, as well.

In the following table, the accident quotients that refer to death per inhabitants, death per vehicles, and a factor b are displayed. The latter refers to numbers of vehicles, inhabitants and driven kilometers (which in China are assessed).

[5] Liu Y. 1996, Vergleich der Straßenverkehrssicherheit zwischen der Volksrepublik China und der alten Bundesrepublik Deutschland, ZVS 40, 4/IV

Table 8: Comparison of PRC and old fedural countries

	Death/10^5 Inh.	Death/10^4 vehicles	b
Ger: 1970	31,64	11,13	0,301
Ger: 1975	24,05	6,99	0,383
Ger: 1976	24,09	6,62	0,394
Ger: 1977	24,39	6,32	0,399
Ger: 1978	23,91	5,85	0,413
Ger: 1979	21,55	5,04	0,446
Ger: 1980	21,18	4,83	0,457
Ger: 1990	12,39	2,21	0,627
PRC: 1990	4,65	52,49	0,407

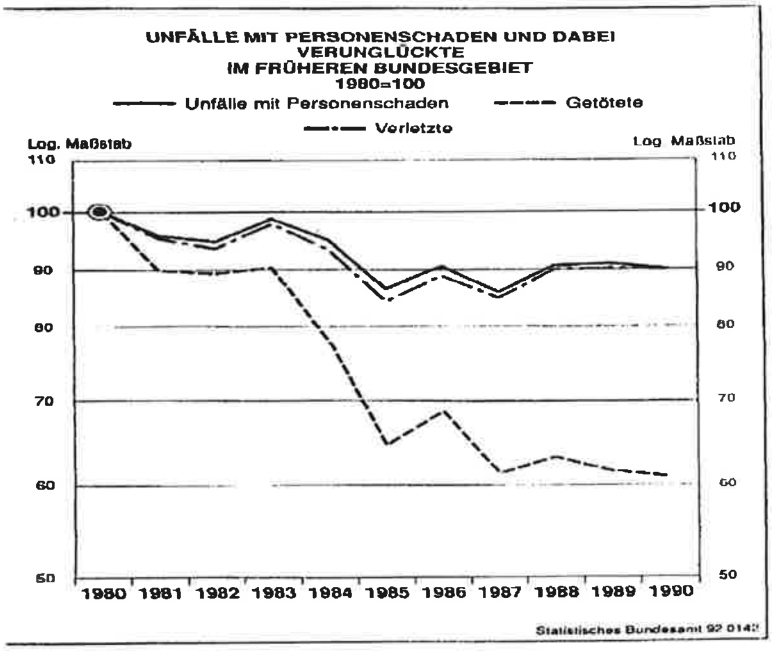
The conclusion of Liu is that the traffic safety standard in the People´s Republic of China 1990 is comparable to the one in Germany (old federal countries) in the years 1977/1978.

7. Accident statistics of the DVR6

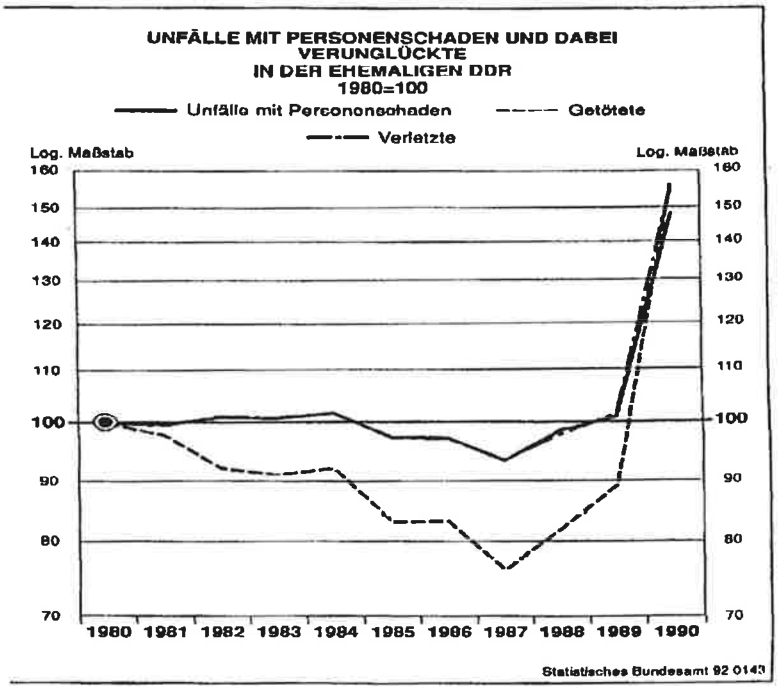
To finish with, two graphs are presented that show the development of accident numbers both in the old and in the new federal countries:

[6] Deutscher Verkehrssicherheits-Rat DVR 1992, Unfallverhütungsbericht Straßenverkehr 1991. Bericht des Bundesministers für Verkehr über Maßnahmen auf dem Gebiet der Unfallverhütung im Straßenverkehr für die Jahre 1990 und 1991; Übersicht Rettungswesen, DVR Drucksache 12/3102

Graph 7: Accident rates, injured and killed persons in former West Germany



Graph 8: Accident rates, injured and killed persons in former East Germany



The results show a very clear difference in the development in former East Germany and former West Germany.

REFERENCES

DEUTSCHER VERKEHRSSICHERHEITS-RAT DVR (1992), Unfallverhütungsbericht Straßenverkehr 1991. Bericht des Bundesministers für Verkehr über Maßnahmen auf dem Gebiet der Unfallverhütung im Straßenverkehr für die Jahre 1990 und 1991; Übersicht Rettungswesen, DVR Drucksache 12/3102

LIPPHARD D. (1994), Geschwindigkeiten in den neuen Bundesländern - Verhaltensänderungen 1991-1993. Neue Fahrbahnen, Ausstattung, Umfeld, ZVS 40, 4/IV

LIU Y. (1996), Vergleich der Straßenverkehrssicherheit zwischen der Volksrepublik China und der alten Bundesrepublik Deutschland, ZVS 40, 4/IV

REKER K., BUSS E. & ZWIELICH F. (1993), Fahrverhaltensbeobachtung im Raum Berlin, Berichte der Bundesanstalt für Straßenwesen

SARTRE (1994), Social Attitudes to Road Traffic Risk in Europe. European Drivers and Traffic Safety, Presses Ponts et Chaussées

SCHULZE H. (1996), Lebensstil und Verkehrsverhalten junger Fahrer und Fahrerinnen, Berichte der Bundesanstalt für Straßenwesen (BASt), Heft 56

APPLICATION OF A QUANTITATIVE EXPERT JUDGEMENT MODEL IN TRAFFIC SAFETY ANALYSIS - a methodological experiment, Urho Pulkkinen & Lars Leden

VTT Automation/VTT Communities and infrastructure

Espoo

Abstract

We describe a risk index model for the evaluation of traffic safety. 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, we incorporate expert judgements into the analysis by a Bayesian additive or multiplicative error model. The final risk estimates are determined by Monte-Carlo simulation. We apply the model in the safety assessment of the effect on collision risk between right turning vehicles and bicyclists when raising a bicycle crossing to roughly the same level as the bicycle path.

1. Introduction

The decision making related to traffic safety is partly based on the assessment of relative risks of different traffic designs. In the risk analyses, various expert opinions are needed and used in addition to empirical data. In the field of engineering risk assessment, the risk is evaluated quantitatively, and various models are applied in the quantification of the accident probabilities and the consequences of the accidents. The models of engineering risk assessment are also often based on experts' opinions. The aim of this paper is to make an experiment on the use of quantitative risk models on traffic safety issues.

The experiment is a part of a project were the safety effects of bicycle paths in Gothenburg is evaluated. Bicycle paths have in recent years been rebuilt to a large extent in Gothenburg. The most common intervention and the one we chose to study was to raise bicycle crossings to roughly the same level as the bicycle paths, in order to reduce the velocity of the motor vehicles and raise drivers attention. Different types of data related to the interaction between cars and bicycles on a bicycle crossing were measured such as speed data for different vehicle and bicycle streams and bicycle volume.

In addition to measured statistical data experts were asked to judge the relationship between different types of measured data and the relative risk. For this experiment on methodology we chose to use data on speeds for right turning cars before and after a bicycle crossing at the intersection of Eklandagatan and Utlandagatan were raised to the level of the bicycle path and marked with red stones to raise drivers attention. This data was used together with experts' judgement on the relationship between right turning vehicle speeds and relative risk to estimate the effect on bicyclists risk of the described intervention.

To be able to use the information from real measurements and experts' assessments and to compare the risk of accident, we constructed a quantitative risk model. In risk assessment of technological systems, similar models are applied routinely (see e.g. Pulkkinen, 1995, Cooke, 1991, McCormick, 1981). The advantages of using quantitative models are obvious: firstly, to create a model one must define the concepts more exactly, which helps to interpret the results, secondly, the use of expert judgements becomes consistent and transparent through models, and the quantitative assessment makes it possible to compare the results.

In this paper we describe a quantitative risk model, which makes it possible to use expert judgements, and apply the model in the case of simple example.

2. The risk model

2.1 Outline Of The Model

The concept of risk is connected with uncertainty on harmful consequences of certain actions. Usually, the uncertainty is interpreted in a probabilistic way and it is measured in terms of probability. Thus, the risk may be defined as the probability of harmful events or as the mathematical expectation of losses due to the harmful events. Often, at least in engineering risk analyses the risk is also defined in terms of the frequency of harmful events (McCormick, 1981). These statistical or probabilistic interpretations of risk are applicable also in the traffic risk studies.

Our risk model consist of the risk index model, the expert assessment model and of the 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 (see section 2.2). In our case the risk index model is a multiplicative attribute model, in which the effect of each attribute on risk may be evaluated separately. The attributes are factors determining the risk. In the case of traffic safety typical attributes are for example the speeds of the vehicles or bicycles, time to accident, etc.. Here, we do not interpret the risk index in a probabilistic way, but it may be directly connected to accident frequency or other statistical measures.

The experts' assessment model is used in incorporating the assessment made by the experts into the quantitative risk evaluation (section 2.3). We adopt the additive or multiplicative error models (Mosleh & Apostolakis, 1984). Depending on the case, also other type of models may be used (Pulkkinen, 1994). We apply a Bayesian approach, in which the distributions of the model parameters are updated on the basis of additional evidence from experts' assessments.

The attribute model describe the statistical properties of the attributes on which the risk depends (section 2.4). 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, and we apply a Bayesian model to determine predictive distributions for the attributes.

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 rather complex way, and the probability distribution cannot be determined without approximate techniques. Here we apply Monte-Carlo simulation (section 2.5)

2.1.1 RISK INDEX MODEL

We assume that the risk is measured by a risk index, R, which is a positive real number. The larger R is the higher is the risk. The risk index R need not to have a probabilistic interpretation, as usually in engineering risk assessment, but it is possible to connect R with accident frequency or accident probability.

The risk index R may depend on several factors or attributes, $x_1,\dots,x_n$. In our case the attributes may correspond to the speed of the cyclist, the speed of the car, or any essential characteristics of the cross roads and the accident situation. The basic assumption of the model is that R depends on the attributes multiplicatively, i.e.

$$R(x_1,\dots,x_n) = R_0 \prod_{i=1}^{n} R_i(x_i)\,, \tag{1}$$

where R_0, $R_1(x_1),\dots,R_n(x_n)$ positive. According to this model each attribute changes the baseline risk, R_0, by a factor, $R_i(x_i)$, which depends on the value of that attribute. Since the risk model is multiplicative, it is easy to study the relative risks of various situations, in which only one of the attributes is varied. If the attribute x_i is varied from x_i^1 to x_i^2 and others are kept constant the relative risk ratio of these two situations is

$$\frac{R(\cdot,x_i^1,\cdot)}{R(\cdot,x_i^2,\cdot)} = \frac{R_i(x_i^1)}{R_i(x_i^2)}\,. \tag{2}$$

In other words, the multiplicative risk model makes it possible to evaluate the impact of each attribute to the overall risk separately. In fact, this assumption is rather analogous to the various independence assumptions applied in multiattribute utility or value functions (see Bunn, 1984). We utilize the separability of the risk index in eliciting and analyzing the expert judgements on the impact of each attributes on the risk.

To make the quantitative analysis possible, we specify the functions $R_i(x_i)$ by assuming that

$$R_i(x_i) = C_i \,\mathbf{exp}(\alpha_i x_i\,), \tag{3}$$

where C_i is a positive constant and α_i is a parameter. The risk index is now

$$R(x_1,\ldots,x_n) = R(\boldsymbol{x}) = R_0 \prod_{i=1}^{n} C_i \exp(\alpha_i x_i) = C \exp\left(\sum_{i=1}^{n} \alpha_i x_i\right). \tag{4}$$

The relative risk with respect to x_i is

$$\frac{R(\cdot, x_i^1, \cdot)}{R(\cdot, x_i^2, \cdot)} = \exp\left[\alpha_i (x_i^1 - x_i^2)\right], \tag{5}$$

which depends only on the parameter α_i and the attribute x_i. According to the above equation we need only to know the parameter α_i to evaluate relative risks of situations where only one of the attributes has been changed.

The above functions $R_i(x_i)$ may have also another forms than the above exponential form. For practical purposes it is beneficial to keep the parametrization of $R_i(x_i)$ simple, and the number of parameters small. Theoretically, it is possible to apply nonparametric approach, but the calculation of the expert assessment model is in that case very difficult.

In real situations the attributes may be unknown and they should be modeled as random variables. As a consequence, R is also a random variable. Generally, the attributes are not statistically independent, and it is not easy to specify the probability distribution of the attribute vector $\boldsymbol{x} = (x_1,\ldots,x_n)$. Further, the determination of the distribution of R may be difficult. However, Monte-Carlo samples are generated easily, if the distribution of $\boldsymbol{x}$ is known.

We may apply the risk index R in comparing risks of situations where the attribute vector has different values. The comparison is based on the ratio of risk indices of the situations.

$$R(\boldsymbol{x}_1, \boldsymbol{x}_2) = \frac{R(x_1^1,\ldots,x_n^1)}{R(x_1^2,\ldots,x_n^2)} = \exp\left(\sum_{i=1}^{n} \alpha_i (x_i^1 - x_i^2)\right), \tag{6}$$

which doesn't depend on the parameters C_i. The relative risk $R(\boldsymbol{x}_1,\boldsymbol{x}_2)$ is sufficient when risks of two situations are compared and if information on the absolute risk index is not needed.

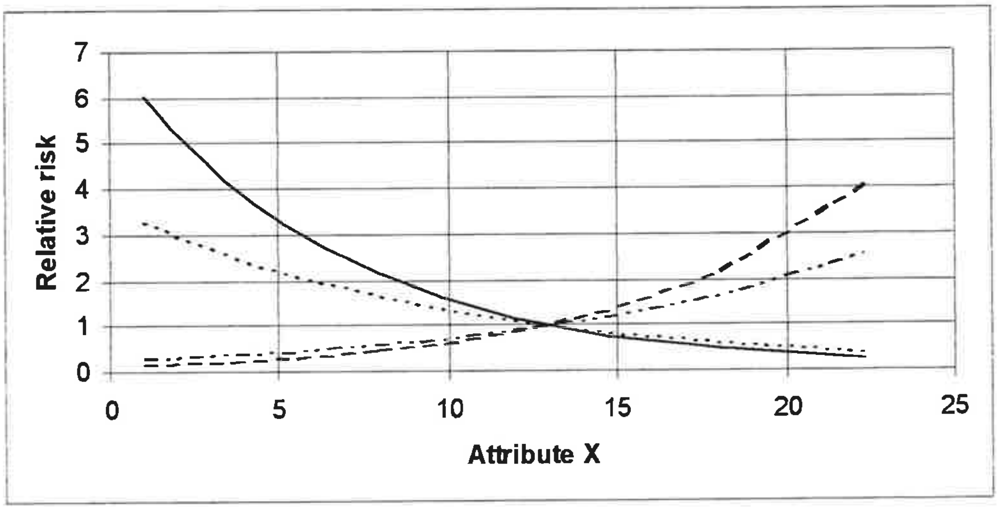
2.1.2 EXPERT ASSESSMENT MODEL

The parameters α_i of the risk index model are not know with certainty, and in principle they could be estimated from empirical accident data. In our case empirical data are missing, and we must use experts' assessments to obtain the numerical values of the parameters. The experts are asked to compare the relative risks of situations, in which one attribute is varied. The comparisons are presented as relative risk curves, where one value of each attribute is interpreted as a reference point x_i^{ref}. The relative risk curve is of the form

$$r_i(x_i) = \frac{R_i(x_i)}{R_i(x_i^{ref})} = \exp\left(\alpha_i (x_i - x_i^{ref})\right), \tag{7}$$

where x_i^{ref} is the reference point. Examples of relative risk curves are given in Figure 1.

***Figure 1**: Relative risk curves.*



Since the experts do not directly assess the value of the parameters α_i, their values must be estimated from the relative risk curves. Often the curves given by experts do not necessarily follow the above exponential form. However, the parameters α_i can be approximately estimated from the graphs by evaluating the (exponential) slope of the curves.

We assume that the number of experts is m. We denote the estimate of expert j for α_i by α_{ij}. The estimate α_{ij} is not equal to the true value α_i, but it is corrupted by additive noise, or

$$\alpha_{ij} = \alpha_i + \varepsilon_{ij}, \tag{8}$$

in which ε_{ij} is a random error. The statistical characteristics of ε_{ij} describe the experts' ability to estimate α_i. Here we assume that the experts are unbiased, i.e. the expected value of ε_{ij} is zero, $E[\varepsilon_{ij}]=0, \ \forall i,j$. The variance of error, denoted by σ_{ij}^2 determines the exerts' ability to produce good estimates: the smaller σ_{ij}^2, the better the expert. In addition to the expected value and the variance we must specify the distribution of ε_{ij} ,, which we assume to be Gaussian, i.e. $\varepsilon_{ij} \sim N(0, \sigma_{ij}^2)$. Furthermore, we assume that the experts' assessments are conditionally independent (given the true values of α_i), or equivalently, that the variables ε_{ij} are independent, or

$$\varepsilon_{ij} \perp \varepsilon_{ik}, \forall i, j. \tag{9}$$

Due to this assumption of independence, we may use the expert assessments on the parameters separately for α_i. Further, we may utilize the assessments of the experts one by one. Our objective is to use the experts' estimates in evaluating the parameters α_i and the uncertainty associated with them. Our approach is Bayesian, and our aim is to update the prior knowledge on the parameters by using the information from experts' assessments. We express the prior knowledge on α_i by a probability distribution, the prior distribution, which we assume to be Gaussian

$$\alpha_i \sim N(\mu_i, \sigma_i^2). \tag{10}$$

The information given by the experts is taken into account by determining the posterior distribution of α_i , which can be determined by using the Bayes formula

$$f(\alpha_i|\alpha_{i1},\ldots,\alpha_{im}) = \frac{L(\alpha_{i1},\ldots,\alpha_{im}|\alpha_i)f(\alpha_i)}{\int_{-\infty}^{\infty} L(\alpha_{i1},\ldots,\alpha_{im}|\alpha_i)f(\alpha_i)d\alpha_i}, \tag{11}$$

where $L(\alpha_{i1},\ldots,\alpha_{im}|\alpha_i)$ is the likelihood function and $f(\alpha_i)$ is the Gaussian prior distribution. Since the experts' estimates follow the Gaussian additive error model and the experts' estimates are conditionally independent, we may write the likelihood function as a product of Gaussian conditional distributions. The likelihood function and the prior distributions are Gaussian, which leads to a Gaussian posterior distribution. The posterior variance is

$$\sigma_{ipos}^2 = \left[\frac{1}{\sigma_i^2} + \sum_{j=1}^{m} \frac{1}{\sigma_{ij}^2}\right]^{-1}, \tag{12}$$

and the posterior expected value is

$$\mu_{ipos} = \frac{\sigma_{ipos}^2}{\sigma_i^2}\mu_i + \sum_{j=1}^{m} \omega_{ij}\alpha_{ij}, \tag{13}$$

where ω_{ij} are weights defined by

$$\omega_{ij} = \frac{\sigma_{ipos}^2}{\sigma_{ij}^2}. \tag{14}$$

In other words, the posterior variance is the harmonic mean of the prior variance and the variances of experts' estimates, and the posterior expected value is a weighted arithmetic mean of the prior expected value and the experts' estimates. The above expert assessment model has been applied in nuclear power plant risk analyses (Mosleh & Apostolakis, 1984). We notice the model is an simple special case of the Kalman filter (see Maybeck, 1979).

The additive error applies to the cases where the variable to be estimated has values from the entire real line. In many practical cases one has to restrict the values of the parameter on positive values of α_i. By assuming that the prior distribution of α_i is lognormal and the experts' estimates α_{ij} follow multiplicative error model, we may apply the above model for the logarithms of the parameters. The multiplicative error model has the form

$$\alpha_{ij} = \alpha_i \cdot \varepsilon_{ij}, \tag{15}$$

in which ε_{ij} is a lognormally distributed error. By taking logarithms we observe that the multiplicative error model behave similarly as the additive error model, and that the parameters of posterior (lognormal) distribution have the same form as those for additive error model.

2.1.3 RISK ATTRIBUTE MODEL

Before going to the determination of risk indices, we must take a look at the distribution of the attribute vectors. In general, the attributes may not be independent and their joint distribution can not be expressed as the product of distributions. However, here we assume the independence between the attributes, and thus the joint distribution is the product of the distributions of single attributes, $g(x_1,...,x_n)=g_1(x_1)\times ... \times g_n(x_n)$.

We assume first that the attributes follow Gaussian distributions (given the parameters θ and v), or $x_i \sim N(\theta_i, v_i^2)$. These distributions are proper models for attributes having values from the entire real line. The attributes having only positive values can be modeled as Gaussian only approximately. To consider attributes having only positive values, we assume that they follow lognormal distributions, i.e. their logarithms follow Gaussian distributions. The parameters θ_i and v_i are unknown, and to make inference on them we adopt again the Bayesian approach.

In our setting we have also empirical data on the values of attributes. The observed values of attribute x_i are $x_{i1},...,x_{ik}$. We denote this evidence by $E_i = \{x_{i1},...,x_{ik}\}$. The likelihood function corresponding to this evidence is given by

$$L(x_{i1},...,x_{ik}|\theta_i,v_i) = \prod_{j=1}^{k} g_i(x_{ij}|\theta_i,v_i) = \prod_{j=1}^{k} \frac{1}{v_i\sqrt{2\pi}} \exp\left[-\frac{(x_{ij}-\theta_i)^2}{2v_i^2}\right] \tag{16}$$

In addition to the likelihood function we need also prior distributions for θ_i and v_i. One possibility is to apply noninformative priors, which give the most weight to the observed data. The noniformative distributions are according to Box and Tiao, (1972),

$$p_\theta(\theta_i) \propto c, \tag{17}$$

and

$$p_{v}(v_i) \propto v_i^{-1}. \tag{18}$$

Further, we assume that θ_i and v_i are (a priori) independent. Due to these assumptions the joint posterior density of θ_i and v_i is (see Box & Tiao, 1972).

$$p(\theta_i, v_i | E_i) = \Psi v_i^{-(k+1)} \exp\left[-\frac{1}{2v_i^2}\left((k-1)s_i^2 + k(\theta_i - \bar{x}_i)^2\right)\right], \tag{19}$$

in which

$$s_i^2 = (k-1)^{-1} \sum_{j=1}^{k} (x_{ij} - \bar{x}_i)^2, \tag{20}$$

$$\bar{x}_i = k^{-1} \sum_{j=1}^{k} x_{ij}, \tag{21}$$

and

$$\Psi = \sqrt{\frac{k}{2\pi}} \left[\frac{1}{2} \cdot \Gamma\left(\frac{k-1}{2}\right)\right]^{-1} \left(\frac{(k-1)s_i^2}{2}\right)^{\frac{k-1}{2}}. \tag{22}$$

In the above equations, $\Gamma(\cdot)$ is the gamma function.

The predictive distribution of the attribute x_i is

$$g_i(x_i | E_i) = \int_{-\infty}^{\infty} \int_{0}^{\infty} \frac{1}{v_i \sqrt{2\pi}} \exp\left[-\frac{(x_i - \theta_i)^2}{2v_i^2}\right] \cdot p(\theta_i, v_i | E_i) d\theta_i dv_i, \tag{23}$$

which describes the uncertainty on the value of x_i updated by the observations E_i. The predictive distribution cannot be determined in closed form, but it is possible to obtain samples from it. To do that, we first use the fact that the marginal posterior of v_i is (Box & Tiao, 1972)

$$p(v_i|E_i) = Yv_i^k \exp\left[-\frac{(k-1)s_i^2}{2v_i^2}\right], \tag{24}$$

where

$$Y = \left[\frac{1}{2}\Gamma\left(\frac{k-1}{2}\right)\right]^{-1}\left(\frac{(k-1)s_i^2}{2}\right)^{\frac{k-1}{2}}. \tag{25}$$

In other words, v_i is distributed a posteriori as $s_i\chi_{k-1}^{-1}\ (k-1)^{1/2}$, in which χ_{k-1}^{-1} is the inverse of the square root of an χ_{k-1}^2 -distributed random variable.

The conditional posterior of θ_i given v_i , is Gaussian

$$p(\theta_i|v_i, E_i) = \frac{\sqrt{k}}{v_i\sqrt{2\pi}}\exp\left[-\frac{1}{2v_i^2}(\theta_i - \bar{x}_i)^2\right]. \tag{26}$$

The sampling from the posterior distribution of v_i is straightforward. First a random variable from χ_{k-1}^2 -distribution is generated and $s_i\chi_{k-1}^{-1}\ (k-1)^{1/2}$ is calculated. Similarly, it us easy to generate from the Gaussian conditional posterior of θ_i. To sample from the predictive distribution, first θ_i and v_i are generated and then x_i is sampled from the Gaussian distribution $N(\theta_i, v_i^2)$.

3. Simulation of model

The risk index $R(x_1,\ldots,x_n)$ and the relative risk index, $R(\mathbf{x}_1,\mathbf{x}_2)$, depend on the parameters $\alpha_i, \ldots, \alpha_n$, and the attribute vectors **x**, which are random variables according to our model. If we assume that the attribute vector is known (i.e. nonrandom), we notice that the exponents appearing in both the risk index and relative risk index (see (4)-(6)) are is a linear function of the parameters. Since the parameters follow Gaussian distributions, these exponents are also Gaussian and their variances and expected values are easily determined. Thus, is the attribute vectors are known, the risk index and the relative risk index are lognormally distributed random variables.

If the attribute vectors are not known, they must be described by their probability distributions. In that case the exponents of appearing in the risk indices exponents are conditionally Gaussian random variables, and finally the risk indices are conditionally lognormal random variables (given the attributes). However, their unconditional distributions are mixtures of lognormal distributions with the predictive distributions of the attributes as mixing distributions. In most cases, these distributions cannot be determined in closed forms. The Monte-Carlo simulation approach, where instead of exact distributions samples from those distributions are produced, seems to be a natural way to analyze the risk indices.

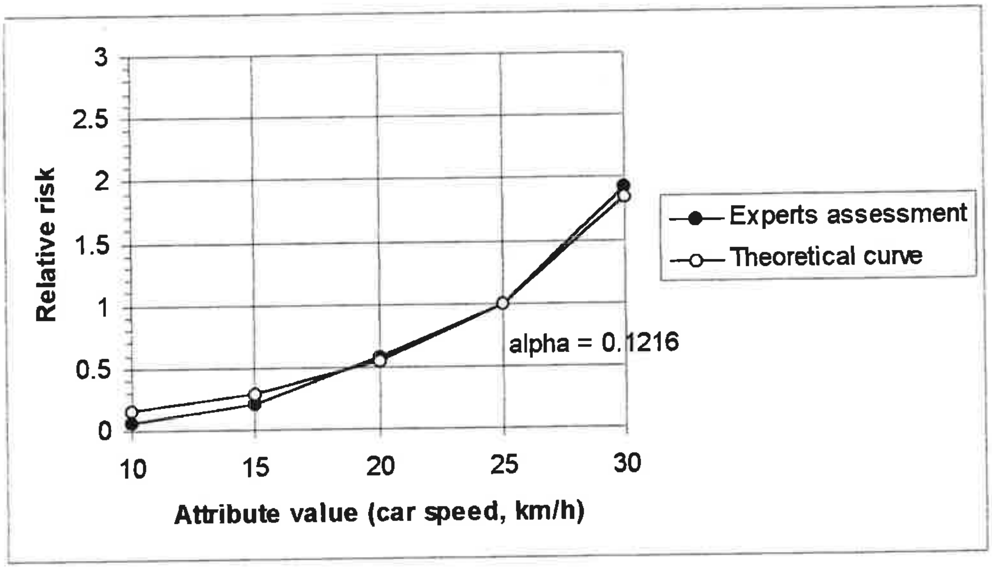
We may generate Monte-Carlo samples for risk indices as follows. First we sample attributes from their predictive distributions as discussed in the previous section (see (17)-(26)). Then we sample the parameters from their posterior distributions (eqns. (13)-(16)). Given these random variables we calculate the values of appropriate risk indices and repeat the procedure to obtain a sample of desired size.

3.1 An Example

We apply the risk model to a simple example, in which the impact of change traffic arrangements is evaluated. The attribute of interest is the speed of right turning cars approaching a bicycle crossing. The raising of the bicycle crossing causes the car speeds to decrease, and we are interested to analyze how the changes is reflected in the risk indices.

First the experts were asked to draw relative risk curves for collision between a bicyclist and car with respect to the speed of a right turning car. We assume that the relative risk curves follow the exponential model defined by (7). The reference speed was 25 km/h. Based on the relative risk curve given by the expert *j*, we estimate the experts' estimate α_{ij} by fitting the exponential curve (7) to the experts' curve. Some relative risk curves given by the experts don't follow the exponential model. This may be due to several facts. First, it is possible that the relative risk doesn't really increase exponentially with respect to the cars speed. In this case, the model for relative risk should be modified, or the risk curve should be specified by using more parameters. Secondly, the nonexponentiality of experts' risk curves may be due to the fact that the experts are not well calibrated. This problem could be avoided by asking the experts to follow the exponential curve and to give directly the estimate for the parameter. An example of a relative risk curve and the fitted exponential curve is given in Figure 2.

Figure 2: The relative risk curve given by an expert.



We determine the Bayesian posterior distributions for the parameter α_i by using the multiplicative error model discussed in section 2.3. The use of multiplicative error model is necessary to obtain positive values for α_i. The prior distribution is a lognormal distribution, or $\alpha_i \sim LN(-0.1,100)$, which correspond to large prior uncertainty. The (multiplicative) errors are also assumed to follow log normal distributions, $\varepsilon_{ij} \sim LN(0,10)$. The experts' estimates, $\alpha_{ij}, j = 1,\ldots,12$ evaluated on the basis of relative risk curves (Figure 2) are listed in table 1. The posterior distribution is lognormal, $\alpha_i \sim LN(-2.702,0.826)$, and the density function is in Figure 3.

__Table 1:__ Experts' estimates for 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 on 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.

Figure 3: The posterior probability density of α_i.

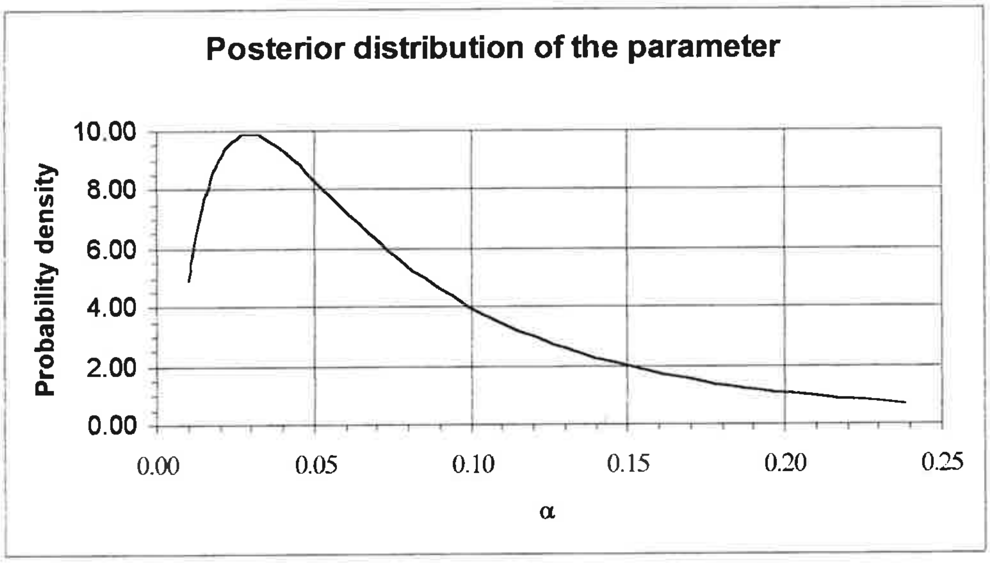
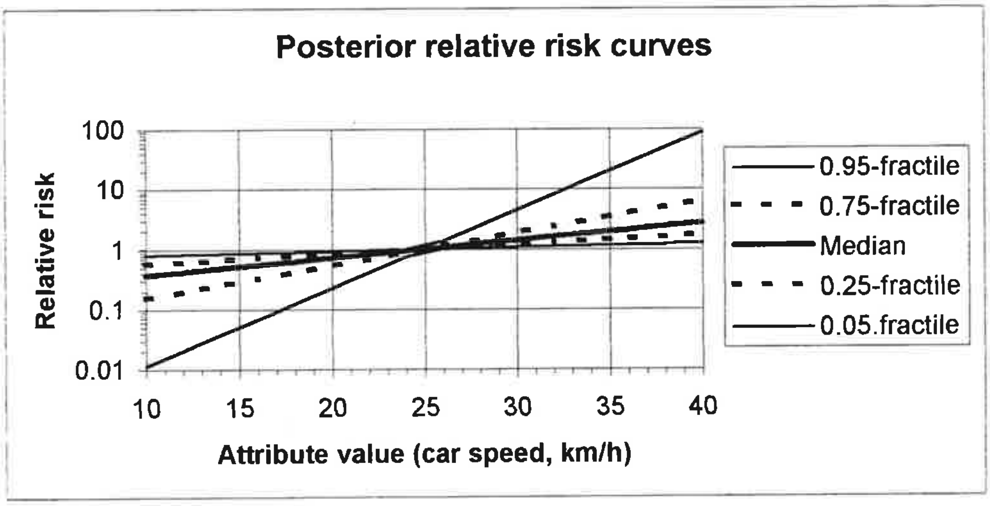


Figure 4: The posterior fractiles of relative risk curves.



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 rather realistic result. Although it is not an easy task to specify the expert judgement model, especially the variance of error term ε_{ij}, the expert model applied here seems to give qualitatively correct results.

To compare risks of two situations one must also determine the predictive distributions of attributes, as discussed in section 3. In our example, the attribute under analysis is the speed of right turning cars coming to a bicycle crossing. The bicycle crossing has been raised and samples on car speeds both before and after were collected. We determine the predictive distributions on the basis of those samples. Since the speed of the car is positive, we assume that it follows a lognormal distribution with unknown parameters and proceed as discussed in section 3. Here we assumed the noninformative prior for the mean value of the logarithm of the cars speed and slightly informative distribution for the variance. The empirical and predictive distributions of car speed both before and after change are shown in Figure 5.

Finally, we present the distributions for risk indices before and after change (see Figure 6). They are determined by Monte-Carlo simulation based on the above distributions. The posterior probability that the situation after change is "less risky" is *0.77*. In addition to the posterior distributions of the risk indices before and after change we present the distribution of the ratio of these risk indices: Risk after/Risk before (see Figure 7). The median of the risk ratio is *0.85*, indicating that the risk is higher before the change of the cross roads. The risk difference is due to the changes of the car speeds, since the parameter α_i is assumed to be the same for situations before and after change.

Figure 5: *The predictive distributions of speed of right turning cars. Empirical data from the intersection of Eklandagatan and Utlandagatan in Gothenburg.*

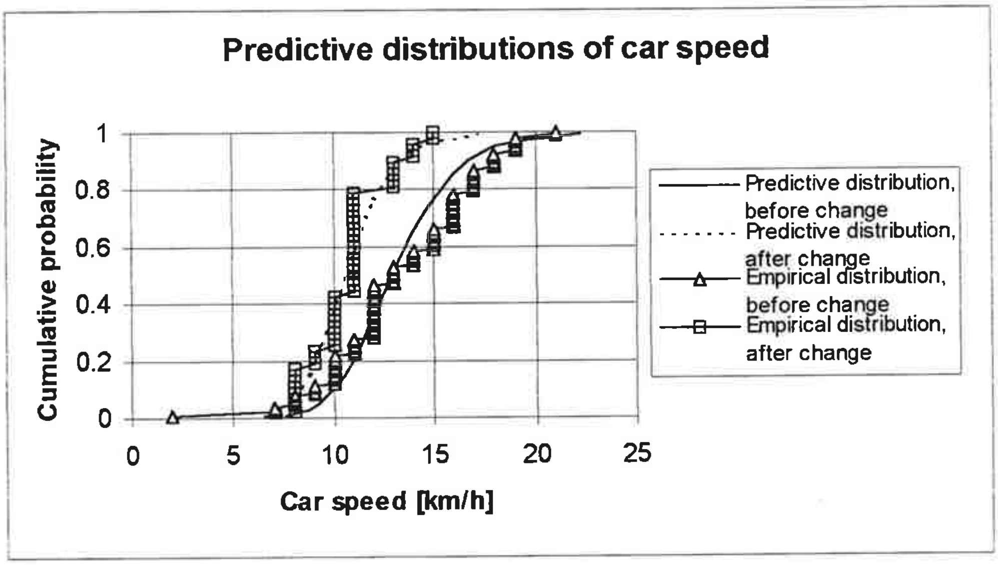


Figure 6: The posterior distributions of risk indices.

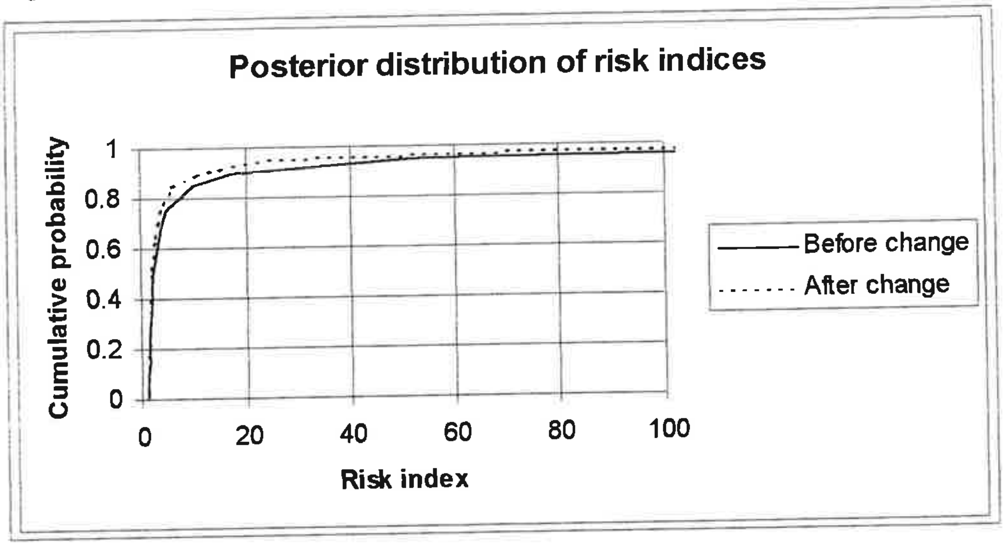
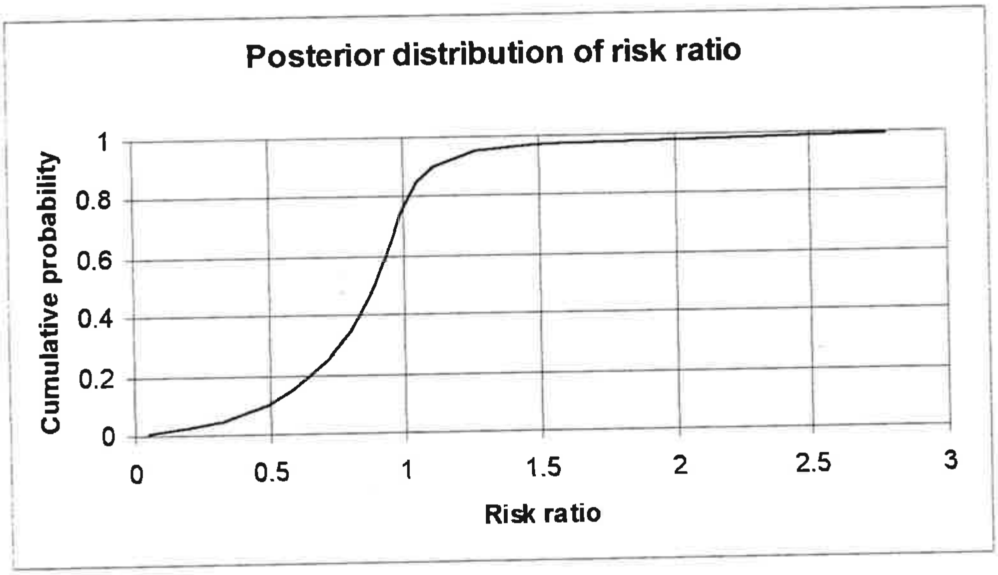


Figure 7: The posterior distribution of the ratio of risk indices (Risk after/Risk before).



4. Concluding remarks

The evaluation of traffic safety in various situations requires often expert assessments in addition to empirical or other "hard" evidence. In this paper we have described experiments with a rather simple risk index model, which makes it possible to use expert assessment quantitatively in the safety evaluation. The core of our model is the multiplicative model, which relates the risk index of the traffic situation with certain attributes (such as the vehicle speeds, bicycle flow, etc.). Due to the multiplicative form of our model, the effect of each attribute may be analyzed separately on basis of simpler models specific to each attribute. In our case, the models were very simple and they could be determined uniquely with one parameter. The multiplicative model may be applied, if the attributes don't have a combined effect on the risk.

The expert assessments on the risk were made separately for each attribute, by using the exponential model. The experts were asked to give their opinions in the form of relative risk curves, from which the parameters 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. The latter leads probably to calculational 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 distributions as possible. Both in the additive and multiplicative error models leads to distributions with large σ (the variance of Gaussian distribution behind the 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 attributes of the risk model are often random variables, which can be modeled by a suitable probability distribution. In order follow the principles of Bayesian statistics, we applied models based on Gaussian distributions. The prior distributions of the parameters of these distributions were noninformative, which lead to rather broad predictive distributions. The predictive distributions in our example were even broader that the empirical distributions based on the observations. This can be avoided by using informative prior distributions.

The calculational problems in determination of the posterior distributions are not restrictive. The application of Monte-Carlo simulation makes it possible to sample from various distributions. The numerical algorithms are also easily implemented into PC-environment. We expect that the extension of the methodology is possible also in the case of large models.

The quantitative approach discussed here give useful results for comparison of risk in various situations. The expert judgements are treated in a consistent way and the uncertainties are interpreted in a probabilistic way. The uncertainty of expert judgements 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, 1995). The methodology is rather mature. On the another hand, the use of quantitative arguments cannot be avoided in decision making related to traffic safety, 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 are treated analytically.

This paper reported an experiment on the methodology, and the results were promising. In future, data for other attributes such as time to accident, bicyclists' speed, bicycle volume etc. can be included in the analysis. To develop the methodology further for day to day use, approaches for sensitivity analysis and specification of prior distributions shall be established. To get more experience on the methodology, more experiments are needed.

5. Acknowledgments

The authors would like to express their sincere appreciation to all those who contributed in various ways in the development of this study. As already mentioned it was done as a part of a project, where the safety effects of bicycle paths in Gothenburg are evaluated. First of all we offer our thanks to the other members of the project team Per Gårder, Per Näsman and Torbjörn Thedéen. A special thanks to all experts answering the expert survey and to the city of Gothenburg for providing us with speed measurements and to Risto Kulmala for presenting this paper at the ICTCT meeting in Paris. Our final thanks go to Swedish Transport & Communications Research Board and Swedish Road Administration for their financial assistance without which this study would not have been possible.

REFERENCES

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.

COOKE R.M. (1991), Experts in uncertainty: Expert opinion and subjective probability in science. Oxford University Press, New York. 321 p.

McCORMICK N.M. (1981), Reliability and risk analysis. Methods and nuclear power applications. Academic Press, New York. 446 p.

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.

BUNN D.W. (1984), Applied decision analysis. McGraw-Hill Book Company, New York. 251 p.

MAYBECK P.S. (1979), Stochastic models, estimation and control. Vols. 1-2. Academic Press, New York. 423+289 p.

BOX G.E.P., TIAO G.C. (1972), Bayesian inference in statistical analysis. Addison-Wesley Publishing Company, Reading. 588 p.

APPLICATION OF A QUANTITATIVE EXPERT JUDGEMENT MODEL IN TRAFFIC SAFETY ANALYSIS - Two Examples Showing the Advantages and Possibilities with the Technique,

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Abstract

We use a risk index model for the evaluation of traffic safety. 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, we incorporate expert judgements into the analysis by a Bayesian additive or multiplicative error model. The final risk estimates are determined by Monte-Carlo simulation. We apply the model in the safety assessment of the effect of elevated cycle crossing causing reduced car speeds and increased bicycle speeds. It seems that the positive effect on collision risk by reduced car speeds is balanced by the increased bicycle speeds, so that the combined effect is plus minus zero. The positive effect on injury risk of reduced car speeds is greater than that on collision risk.

1. Introduction

The decision making related to traffic safety is partly based on the assessment of relative risks of different traffic designs. In the risk analyses, various expert opinions are needed and used in addition to empirical data. In the field of engineering risk assessment, the risk is evaluated quantitatively, and various models are applied in the quantification of the accident probabilities and the consequences of the accidents. The models of engineering risk assessment are also often based on experts´ opinions.

The experiment is related to a project were the safety of bicycle paths in Gothenburg is evaluated. The evaluation is based partly on the opinions by experts, who evaluate the impact of several factors on the safety of bicycle paths. Bicycle paths have since 1992 been rebuilt to a large extent in Gothenburg. The most common intervention and the one we chose to study was to raise bicycle crossings to roughly the same level as the bicycle paths, in order to reduce the velocity of the motor vehicles and raise drivers attention. Different types of data related to the interaction between cars and bicycles were measured such as conflicts, simulated conflicts, time to accidents, Post Encroachment time (PET), speed data for different vehicle and bicycle streams.

In addition to measured statistical data experts were asked to judge the relationship between the different types of measured data and the relative risk. For this paper we chose to use data on speeds for and on right turning cars before and after a bicycle crossing at the intersection Första Långgatan and Sänkverksgatan were raised to the same level as adjacent bicycle paths and marked with red stones to raise drivers attention. This data was used together with experts judgement on three relationships: first one between bicycle speeds and relative risk; second one between right turning vehicle speeds and relative risk and third one between right turning vehicle speeds and injury risk to estimate the effect on bicyclists risk of the described intervention.

To be able to use the information from real measurements and experts' assessments and to compare the risk of accident, we constructed a quantitative risk model. In risk assessment of technological systems, similar models are applied routinely (see e.g. Pulkkinen, 1994, Cooke, 1991, McCormick, 1981). The advantages of using quantitative models are obvious: firstly, to create a model one must define the concepts more exactly, which helps to interpret the results, secondly, the use of expert judgements becomes consistent and transparent through models, and the quantitative assessment makes it possible to compare the results.

This paper gives two examples showing the advantages and possibilities on the use of quantitative risk models in the traffic safety. The aim of this paper is to show the advantages and possibilities with the technique. It also gives an outline of the quantitative risk model. For detailed information about the theoretical background see Pulkkinen & Leden (1996).

2. Outline of the model

Our risk model consist of the risk index model, the expert assessment model and of the 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. In our case the risk index model is a multiplicative attribute model, in which the effect of each attribute on risk may be evaluated separately. The attributes are factors determining the risk. In the case of traffic safety typical attributes are for example the speeds of the vehicles or bicycles, time to accident, etc.. Here, we do not interpret the risk index in a probabilistic way, but it may be directly connected to accident frequency or other statistical measures.

The experts' assessment model is used in incorporating the assessment 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 type of models may be used (Pulkkinen, 1994). We apply a Bayesian approach, in which the distributions of the model parameters are updated on the basis of additional evidence from experts' assessments.

The attribute model describe 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, and we apply a Bayesian model to determine predictive distributions for the attributes.

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 rather complex way, and the probability distribution cannot be determined without approximate techniques. Here we apply Monte-Carlo simulation.

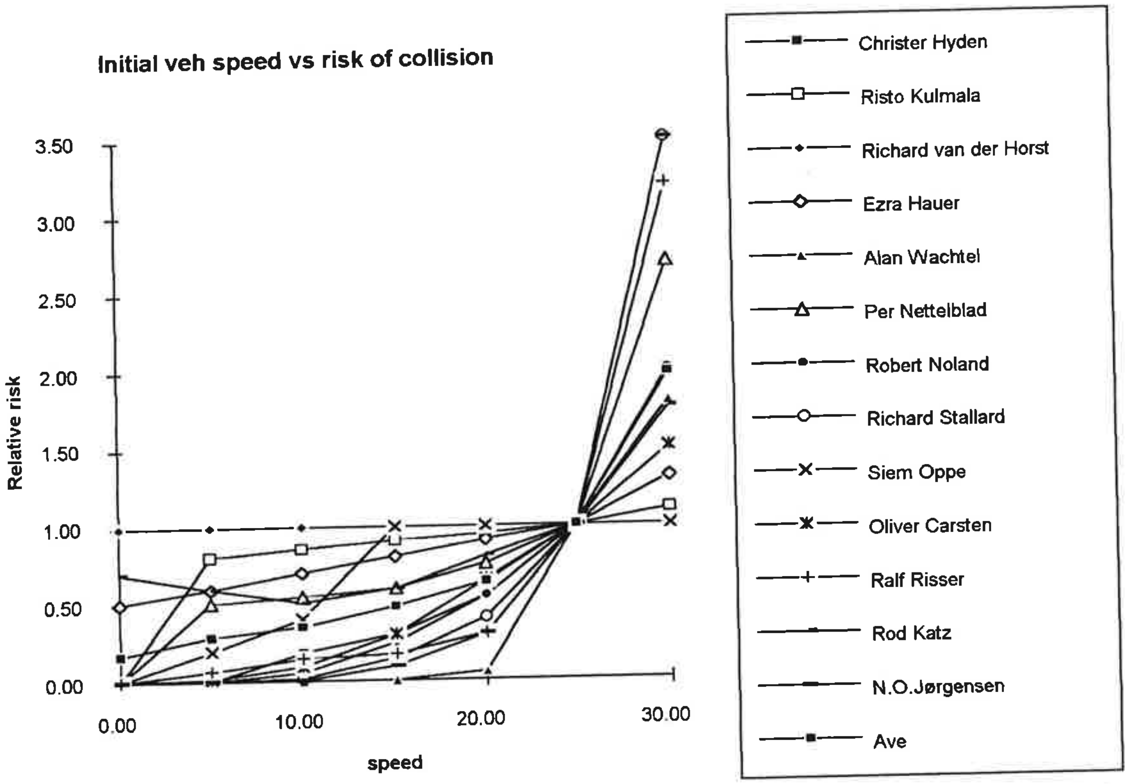
2.1 First Example

Let us apply the model on the first example. It has two attributes car speed and bicycle speed. It examines their combined effect on collision risk.

The experts were asked to draw relative risk curves for collision between a bicyclist and a car with respect of the initial speed of a right turning car and with respect of the speed of the cyclist on the cycle crossing. The experts were also asked to draw relative curves for injury risk between a bicyclist and a car with respect of the initial speed of a right turning car. In the first example we will use the information concerning collision risk. In the second example the information concerning injury risk.

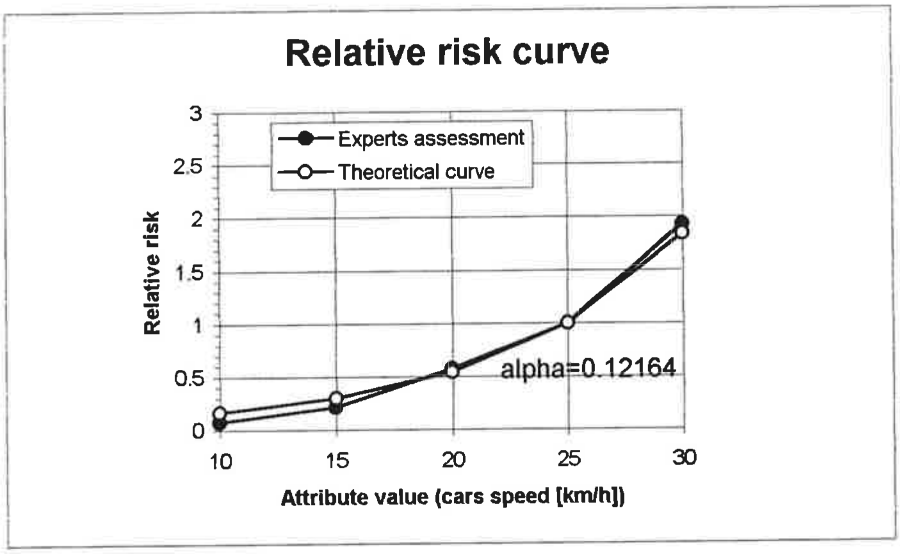
In Figure 1 the original curves, describing relationship between vehicle speed and risk of collision (assuming risk is 1 when speed prior to the evasive action is 25 km/h), drawn by experts are shown in a somewhat simplified form. The experts' estimates α_{ij} for this case were listed in Table 1.

Figure 1: Original curves, describing relationship between vehicle speed and risk of collision, drawn by experts shown in a somewhat simplified form (assuming risk is 1 when speed prior to the evasive action is 25 km/h).



The experts were among other things asked to draw relative risk curves for collision between a bicyclist and car with respect to the speed of a car. We assume that the relative risk curves follow an exponential model. The reference speed was 25 km/h. Based on the relative risk curve given by the expert *j*, we estimate the experts estimate α_{ij} by fitting the exponential curve to the experts curve. An example of a relative risk curve and the fitted exponential curve is given in Figure 2.

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 in table 1. The posterior distribution is lognormal, $\alpha_i \sim LN(-2.702,0.826)$, and the density function is in Figure 3.

Table 1: Experts' estimates for 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 on 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.

Figure 3:. The posterior probability density of α_i.

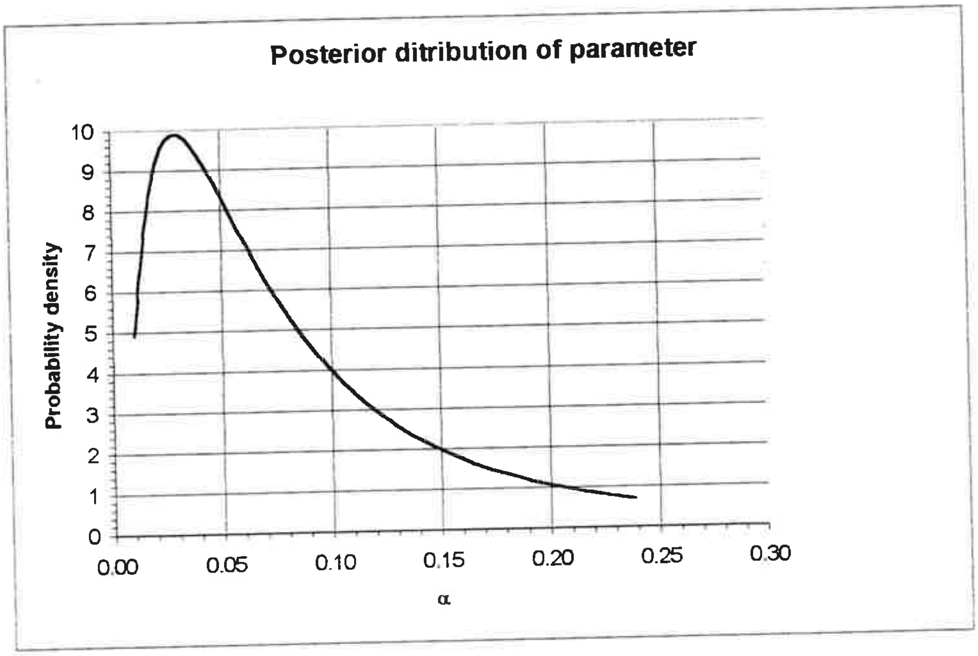
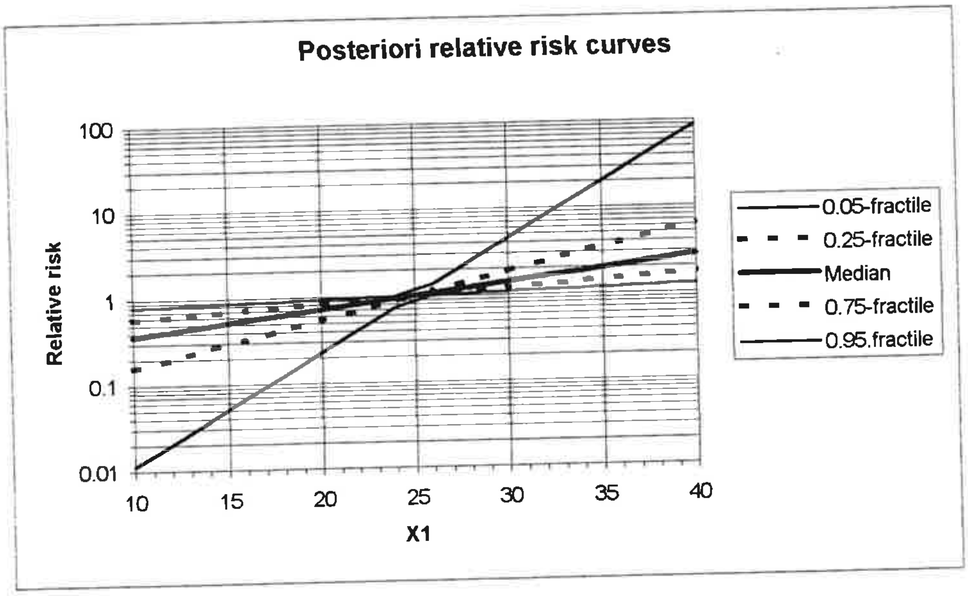


Figure 4. The posterior fractiles of relative risk curves for different speeds (km/h).



The posterior relative risk curves are still rather uncertain: for example, the *90%* probability interval for the relative risk of the car speed at $35kmh^{-1}$ is approximately *(1,20)*. This means that the information from the expert assessments is not very strong, which is 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 correct 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 5: *The predictive distributions of speeds of right turning cars. Empirical data from the intersection of Första Långgatan and Sänkverksgatan.*

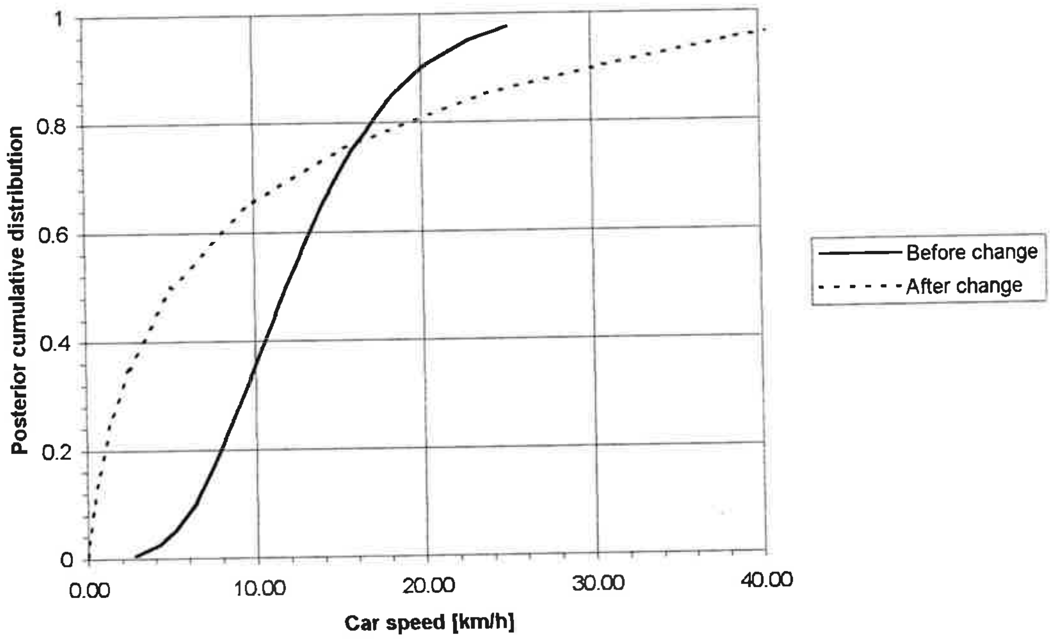
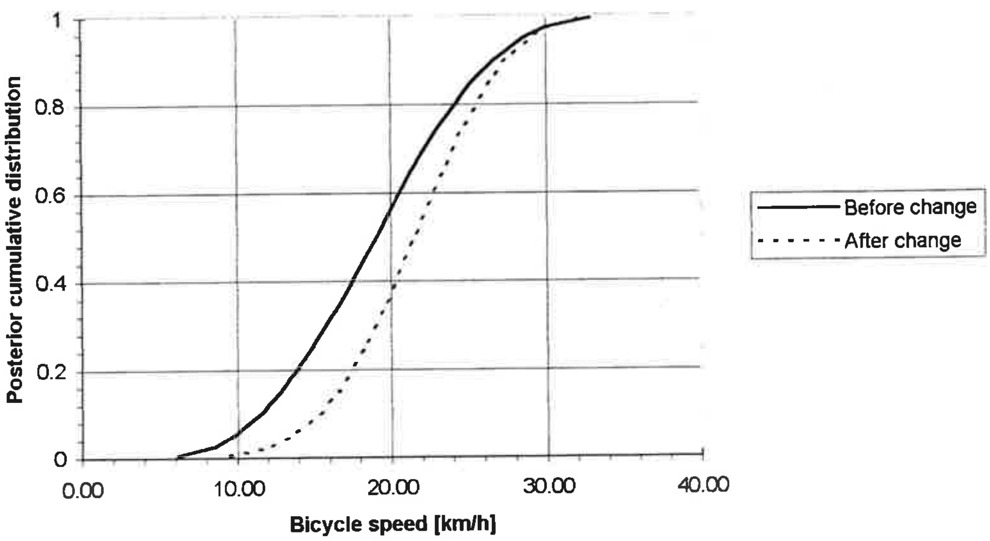


Figure 6: The predictive distributions of speeds of bicyclists. Empirical data from the intersection of Första Långgatan and Sänkverksgatan.



As empirical data also shows right turning car speeds were reduced and bicycle speeds increased. Mean speed for right turning cars into Sänkverksgatan was reduced from 12,2 to 7,4 km/h and mean speed for bicyclists 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 risk ratio is 0,76, indicating that the risk is higher before the change.

Figure 7: The posterior distribution of the ratio of collision risk indices based on right turning car speeds.

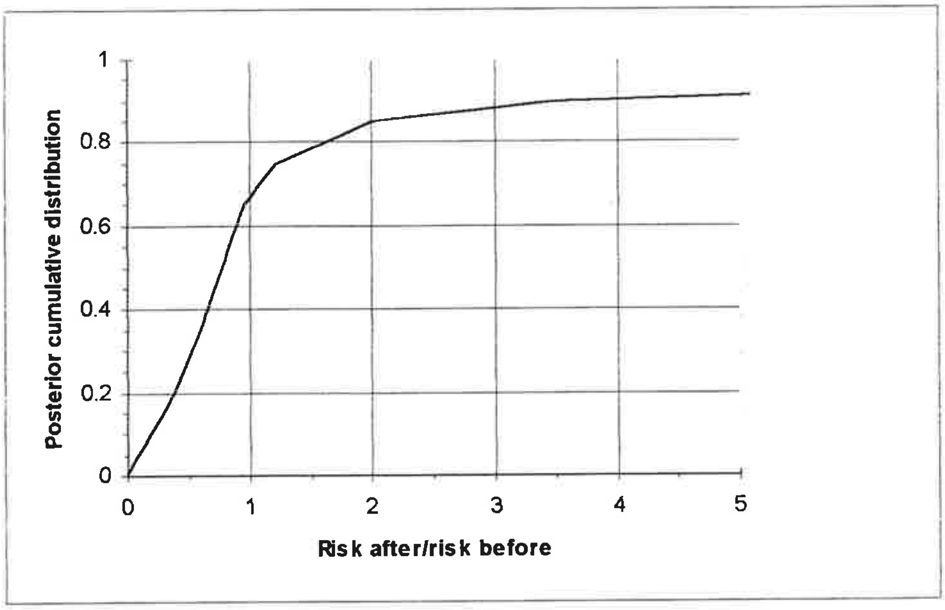


Figure 8 shows the posterior distribution of the ratio of risk indices based on bicycle speeds before and after the intervention. The median of the risk ratio is 1,4, indicating that the risk is higher after the change

Figure 8: The posterior distribution of the ratio of collision risk indices based on bicycle speeds changes.

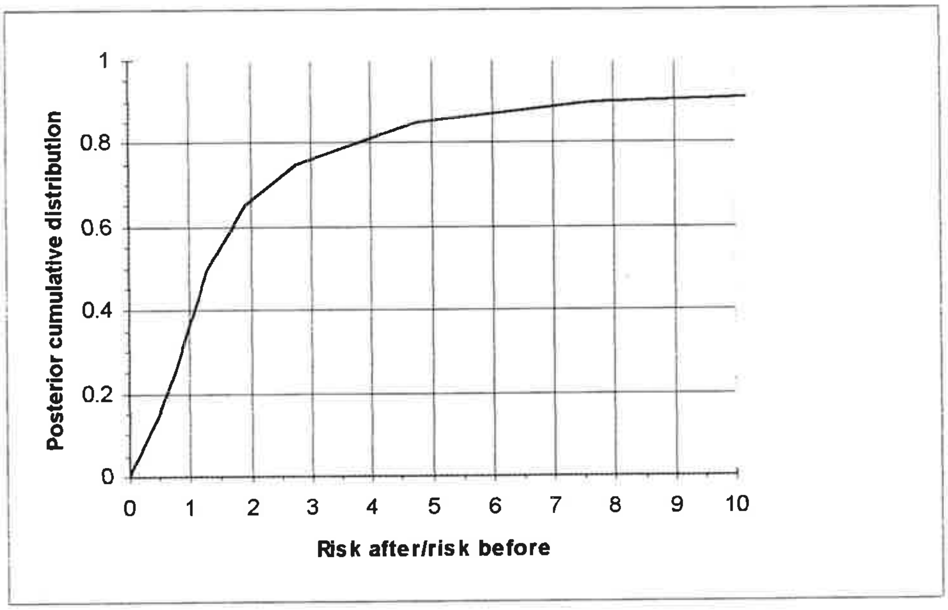
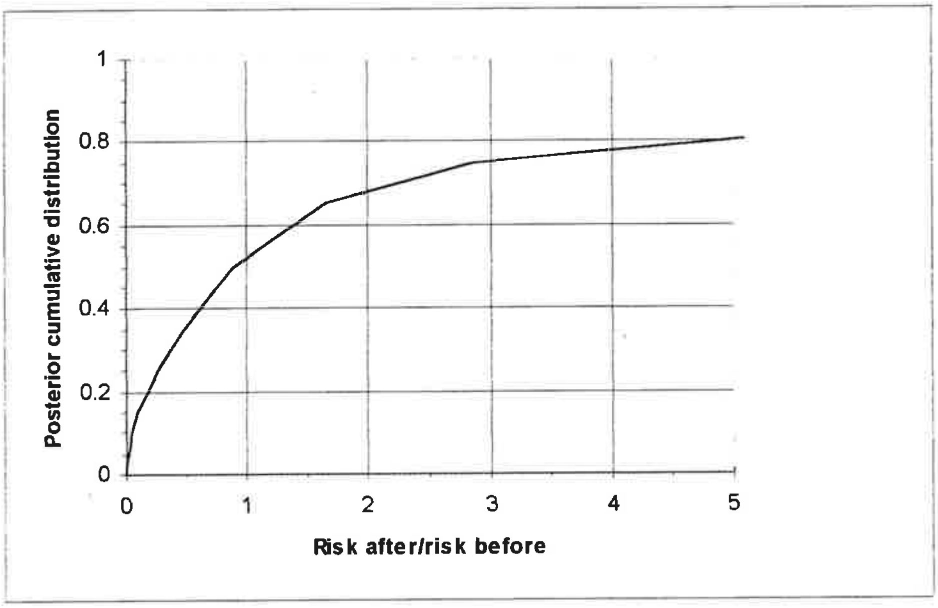


Figure 9 shows the combined risk indices resulting from decreasing car speeds and increasing bicycle speeds. The median of the risk indices are 0,9 indicating a small risk decrease. Roughly speaking it seems that the positive effect on traffic safety by reduced car speeds is balanced by the increased bicycle speeds, so that the combined effect is plus minus zero.

Figure 9: The posterior distribution of the combined collision risks indices based on car and bicycle speed changes.



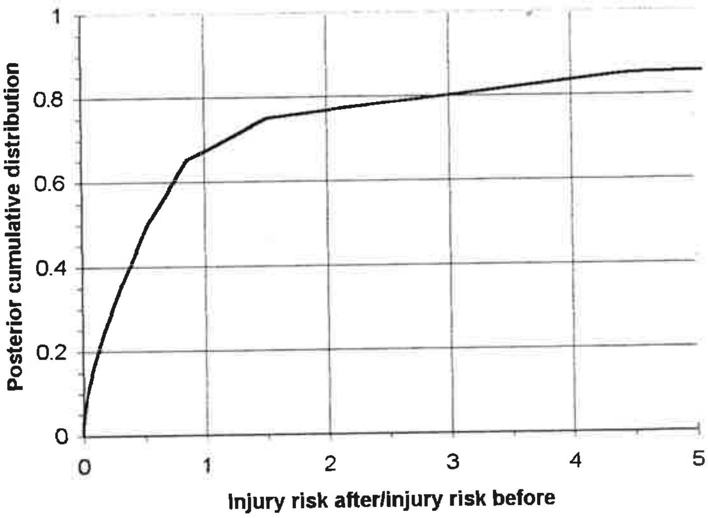
This was the first example exploring the combined effect of reduced car speeds and increased bicycle speeds.

2.2 Second Example

The second example explores how the estimates are effected if injury risk is estimated instead of collision risk.

Figure 10 shows the posterior distribution of the ratio of injury risk indices based on right turning car speeds before and after the intervention. The median of the risk ratio is 0, 5, indicating that the risk is higher before the change. This should be compared to the median 0,75 calculated above for the ratio of collision risk indices. As expected the injury risk is reduced more than the collision risk. This indicates that the combined effect of decreasing car speeds and increasing bicycle speeds could have a positive effect on injury risk. However no special simulations were made on this topic. This topic is left for future research.

Figure 10: The posterior distribution of the ratio of injury risk indices based on right turning car speeds.



3. Concluding remarks

The evaluation of traffic safety in various situations requires often expert assessments in addition to empirical or other "hard" evidence. In this paper we have described experiments showing the advantages and possibilities using a rather simple risk index model, which makes it possible to use expert assessment quantitatively in the safety evaluation. The core of our model is the multiplicative model, which relates the risk index of the traffic situation with certain attributes (such as the vehicle speeds etc.). Due to the multiplicative form of our model, the effect of each attribute may be analyzed separately on basis of simpler models specific to each attribute. The multiplicative model may be applied, if the attributes don't have a combined effect on the risk.

The expert assessments on the risk were made separately for each attribute, by using the exponential model. The experts were asked to give their opinions in the form of relative risk curves, from which the parameters 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 leads probably 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 distributions as possible. Both in the additive and multiplicative error models leads to distributions with large σ (the variance of Gaussian distribution behind the 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 attributes of the risk model are often random variables, which can be modeled by a suitable probability distribution. In order follow the principles of Bayesian statistics, we applied models based on Gaussian distributions. The prior distributions of the parameters of these distributions were noninformative, which lead to rather broad predictive distributions. The predictive distributions in our example were even broader then the empirical distributions based on the observations. This can be avoided by using informative prior distributions.

The calculational problems in determination of the posterior distributions are not restrictive. The application of Monte-Carlo simulation makes it possible to sample from various distributions. The numerical algorithms are also easily implemented into PC-environment. We expect that the extension of the methodology is possible also in the case of large models.

The quantitative approach discussed here give useful results for comparison of risk in various situations. The expert judgements are treated in a consistent way and the uncertainties are interpreted in a probabilistic way. The uncertainty of expert judgements 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, 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 are treated analytically.

This paper reported two examples showing the advantages and possibilities with the technique. We have pointed out a feasible way to model a crucial traffic safety problem with two dimensions: an intervention causing reduced car speeds and increased bicycle speeds. The total effect on collision risk have been calculated indicating “no effect”. Furthermore we have shown a method to model both effects on collision and injury risks and our example shows how important it is to use both approaches.

5. Acknowledgments

The authors would like to express their sincere appreciation to all those who contributed in various ways in the development of this paper. First of all we would like to thank Swedish Road Administration, especially Hans Rydgren and Swedish Transport & Communications Research Board, especially Nils Edström and Lars Wede, for financial assistance for the work, without which this study would not have been possible.

Two types of basic data were needed for the research: expert survey data and field measurements. We would like to thank Per Gårder, University of Maine for his skillful work designing the expert survey questionnaire and for the execution of the survey together with Björn Bergman, Royal Institute of Technology. We would like to thank the City of Gothenburg for the financial assistance for field measurements and especially Lennart Andersson, who were responsible for the measurements. We would also like to thank the other members of the project team Åke Claesson, Per Gårder, Per Näsman and Torbjörn Thedéen and the members of ICTCT for many inspiring and fruitful discussions.

REFERENCES

COOKE R.M. (1991), Experts in uncertainty: Expert opinion and subjective probability in science. Oxford University Press, New York. 321 p.

McCORMICK N.M. (1981), Reliability and risk analysis. Methods and nuclear power applications. Academic Press, New York. 446 p.

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. (1996), 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.

SPEED-REDUCING MEASURES FOR 80 KM/H ROADS, Richard van der Horst

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Abstract

Control of driving speeds offers an important possibility to improve traffic safety on rural 80 km/h roads. In The Netherlands, about 50% of all people killed in traffic occur at these roads, partly due to high speeds. An experimental project in Drenthe was aimed at the development and testing of measures that effectively reduce speed without significantly reducing driving comfort up to speeds of 80 km/h. First, some variants of proposed infrastructural measures were tested in a driving simulator before actual application. Secondly, a resulting set of four basic design elements was implemented on four 80 km/h road sections in Drenthe and evaluated in terms of the actual driving behaviour, including both speed and lateral placement.

In the simulator study, the experimental conditions consisted of two lane-widths (2.75 and 2.25 m) and three experimental lay-outs of edge strips, viz. one with a continuous profiled road marking, one with small lateral rumble strips every 5 meter, and one every 10 meter. On entering this edge strip (the 2.75 m lane had a strip of 0.20 m and the 2.25 m lane one of 0.70 m) auditive feed-back by means of sound and steering-wheel vibration was generated. A conventional 80 km/h road (lane-width 2.75 m) with standard road delineation served as control condition. Two instructions (relaxed vs. driving under time-pressure) were varied between subjects.

The results show that the narrow lane width (2.25 m + 0.70 m edge strip) gives the largest speed reductions and is fairly resistent to effects of adaptation. Moreover, the narrow lane width especially reduces the speeds of drivers under time-pressure, implying that also in practice speed variance may be reduced. The different lay-outs of the edge strips reveal relatively small differences in driving behaviour. In summary, it is concluded that the basic design elements as developed in this project offer a good prospective for reducing driving speeds in practice.

The evaluation of the resulting set of measures on four test locations in Drenthe, based upon the analysis of inductive loop data, indicated that a sustainable speed reduction of about 2 km/h was achieved. Video-observations revealed that, in spite of the reduced lane width of smooth asphalt, the 0.30 m central chipping strip marking (instead of 0.10 m conventional central marking) results in a lateral placement of minimally 0.10 m away from the centre of the road. Apparently, drivers refer mainly to the near-by side of the central marking. So, with respect to lateral placement no negative safety effects have to be expected. Over a two-year period a 20% reduction in the number of accidents was reached, whereas at the control locations an 8% increase occurred.

1. Introduction

In The Netherlands, rural 80 km/h roads have the highest accident rates of all road types. In general, high speed is assumed to contribute substantially to the occurrence of these accidents. Therefore, reduction of driving speeds may offer a high potential for improving traffic safety on 80 km/h roads. The experimental project "Speed Reducing Measures on 80 km/h Roads in Drenthe" - Drenthe being one of the 12 Provinces in The Netherlands - was started in 1990 and aimed at the development and testing of measures that effectively reduce driving speed without significantly reducing driving comfort up to speeds of 80 km/h. At speeds above 80 km/h an increasing discomfort was aimed for. Especially, measures to the road and/or road-environment were explored that result in a 'natural' lower speed choice by the motorist and also reduce speed variance among cars. Measures of this type are well in line with recent developments of Sustainable Road Safety and Self-Explaining Roads (Koornstra et al., 1992, Theeuwes & Godthelp, 1992).

By including knowledge of human information processing and of driver behaviour, in brainstorm sessions with representatives from the local, regional and national government, research institutes, consultancies, and police, a package of basic design elements for 80 km/h roads was identified and compiled (Heidemij, 1992). Some variants of the proposed measures were tested in a driving simulator study with respect to driving behaviour (van der Horst & Hoekstra, 1992; 1994). The resulting design elements were further optimized by computer simulations by testing some roadsurface unevenness patterns on vehicle comfort and tyre-road contact (Hoogvelt & Jansen, 1992). The final package of speed-reducing measures was implemented on four experimental 80 km/h roads in Drenthe and evaluated in terms of speed behaviour and traffic safety for a period of over two years.

2. Speed-reducing measures

In a literature review on determining factors of speed choice, Tenkink (1988) distinguishes several behavioural models, of which the utility model is the most general one. Speed will be reduced when the risk or discomfort caused by an high speed increases. In weighing the pros and cons of an high speed, both the probability and the size of the consequences are important. For example, Tenkink (1989) found a reduction in speed when a narrow road width was combined with threatening obstacles along the road. But also perceptual speed adaptation, uncertainty, and task demand may play a significant role in drivers' speed choice. Negative consequences of a high speed (discomfort, threat) may be effective if they are consistent and real, and if the involved risk is detectable, recognizable, and verifiable. Although an increasing threat, uncertainty, or workload may reduce speed, traffic safety may not necessarily improve as well (Tenkink & van der Horst, 1991). Since drivers may react differently to given measures, with a possible increase in speed variance, measures must provoke uniform behaviour to the greatest extent as possible. Furthermore, on a narrow road the visual guidance may be better than on a wide road, which may result in an increase in speed. These considerations resulted in a basic design for 80 km/h roads consisting of four main elements, viz.: lane width, edge marking, centre marking, and verge reminders (Heidemij, 1992).

Lane Width

An important basic assumption in the design is that the net available lane width for car drivers is reduced as much as possible. It takes some manoeuvring effort to make use of the so-called "smooth" asphalt part of the lane. Deviations from the right course must result in discomfort at speeds above 80 km/h, but without inducing unsafe situations. Another constraint is to ensure that heavy vehicles (trucks, buses) are not impeded at speeds up to 80 km/h. In order to meet both requirements a net lane width of "smooth" asphalt between 2.25 and 2.75 m was proposed, together with a profiled edge marking that makes up a total road width of 6.20 m.

Edge Marking

A second assumption of the basic design is that no excessive visual guidance should be present. Therefore, it was proposed to implement no visual edge marking by delineation, but to use a "tangible" one instead in combination with the additional width needed for heavy vehicles. This edge marking must be designed in such a way that drivers of heavy vehicles do not notice much discomfort, but drivers of passenger cars experience discomfort that increases with speed.

Centre Marking

Reducing the visual guidance by the edge markings requires drivers to get their information on the course of the road primarily from the centre markings. The centre marking must be clearly visible (also during darkness and bad weather) and represent a unique code for 80 km/h roads. Therefore, a 0.30 m centre line (instead of a 0.10 m one) with 3 m long white lines at a 9 m spacing was proposed, preferably with a "tangible" component.

Verge Reminders

In The Netherlands, reflectors posts at a height of 0.60 m every 40 m usually support the visual guidance. To reduce the visual guidance these road-side reflectors are removed and replaced every 500 m by so-called verge reminders uniquely designed for 80 km/h roads.

In the simulator study, these four basic elements in the road design of 80 km/h roads

were included.

3. Simulator study

3.1 Method

The aim of the simulator study is to gain insight in the functioning of the proposed measures in terms of driving behavior before measures are actually implemented on the road. In general, results from simulator studies with respect to speed choice indicate that the relative validity is acceptible (Riemersma et al., 1990; Tenkink, 1990; Tenkink & van der Horst, 1991). However, absolute speed levels have to be interpreted with caution because one tends to drive faster in a driving simulator than in the real world.

The experiment was conducted in the fixed-base driving simulator of the TNO Human Factors Research Institute. At the time of the experiment, this simulator had a MEGATEK 944 CGI-system that generated the visual scene (1024 x 1024 pixels) at a refresh-rate of 30

Hz. These images were displayed on a large screen in front of the vehicle mock-up (a Volvo 240) by a high resolution projector BARCOGRAPHICS 800 (van der Horst, Janssen & Korteling, 1991). The horizontal visual angle of the projected image was about 50 angular degrees. Nowadays, the TNO driving simulator has been equipped with a three channel Evans & Sutherland ESIG 2000 CGI system, enabling a horizontal visual angle of 120 degrees. Recently, a simple moving base system (MOOG 6DOF2000E) has been added (Hoekstra, van der Horst & Kaptein, 1997).

The independent variables of the simulator-experiment included: instruction (relaxed, time-pressure), lane width (2.25 m and 2.75 m smooth asphalt), and edge-stripe configuration (continuously profiled marking strip, small cross rumble strips every 5 m, and small cross rumble strips every 10 m). The centre line of the experimental roads consisted of a 0.30 m continuous profiled marking with every 12 m a series of three white blocks of 0.80 x 0.30 m at a mutual distance of 0.30 m. Entering the centre or edge marking with one of the wheels resulted in an auditive feed-back to the driver via a loud sound in the vehicle and a vibration in the steering wheel. At the beginning of each experimental road the symbol "80" was painted on the road surface A standard rural road with conventional delineation, a lane width of 2.75 m, and post mounted reflectors every 40 m, served as a control condition. Each subject drove each condition three times.

In total, 32 male subjects participated in the experiment. The age varied between 21 and 53 years (average 35.5). Subjects were paid for their participation.

Dependent variables included speed, standard deviation (s.d.) of speed, lateral position, s.d. of lateral position, and the number and duration of left and right lane exceedances. Separate analyses of variance (ANOVAs) have been conducted on the driving behaviour variables on straight road sections and in curves (100 m before and 100 m after the curve included). For a more extensive description of the experiment the reader is referred to Van der Horst and Hoekstra (1992, 1994).

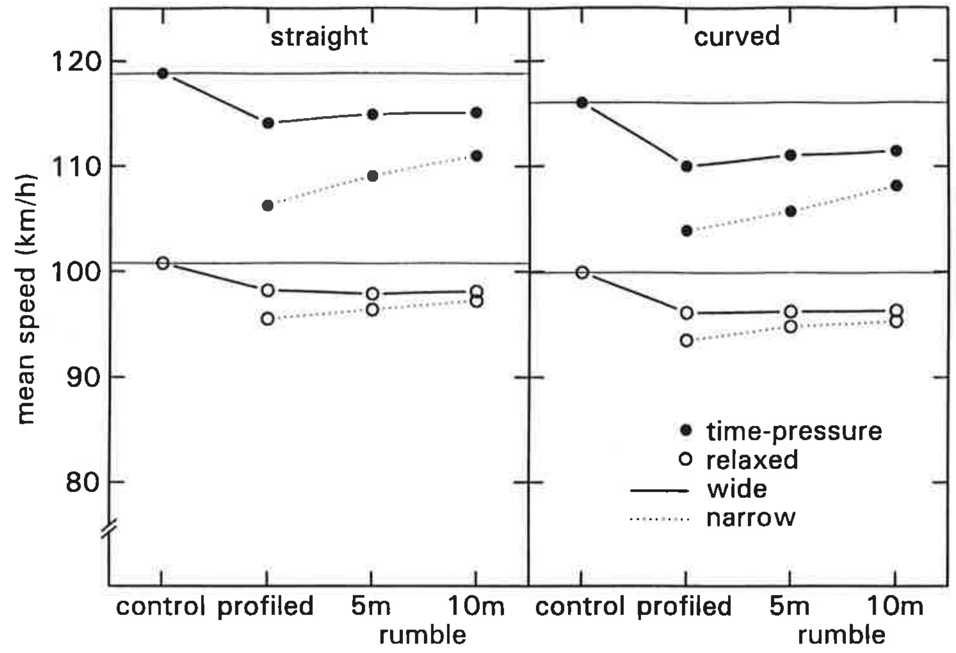
3.2 Results

Speed

The proposed measures aimed at reducing speed. Figure 1 gives the speed, averaged over subject, and repetition, as a function of instruction, lane width ("smooth" asphalt) and the three experimental configurations of the edge strip. The results of the control condition with the conventional 80 km/h road are added as a reference. The absolute speed levels appear to be often rather high in a driving simulator. Also in this study, even for the instruction relaxed driving the absolute speed values are well over 80 km/h. Instruction has an important effect on speed. Subjects under time pressure drive about 15 km/h faster on the straight road sections (113 vs. 98 km/h, $F(1,228)=15.0$, $p<0.001$), and 14 km/h faster in curves (110 vs. 96 km/h, $F(1,28)=10.9$, $p<0.005$). The main effect of lane width just does not reach significance ($F(1,28)=3.6$, $p<0.07$). It appears that under time pressure the speed on the narrow lanes is significantly lower than on the wide lanes (t-test, $t=3.4$, $p<0.002$). A narrow lane especially reduces the speed of the drivers that are in a hurry. The three edge strip configurations differ only for the narrow lane width (interaction width x configuration

F(2,56)=7.5, p<0.002). In combination with the narrow lane width, the configuration with the continuous profiled marking reduces speed speed somewhat more than the two other configurations. So, the configuration with the most direct feed-back to the driver gives the best results.

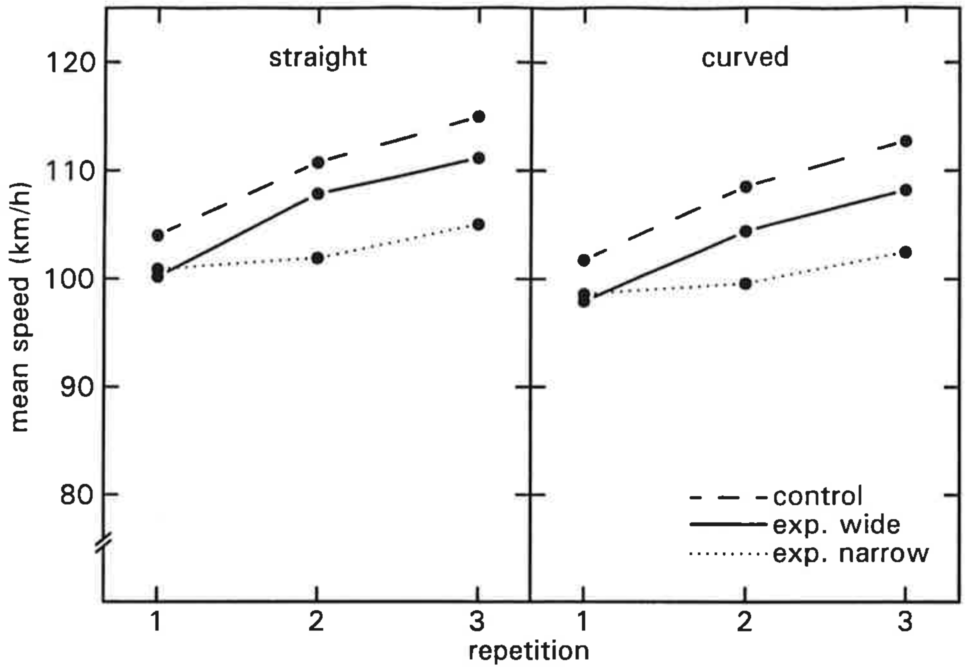
Figure 1: Speed on straight (left) and curved (right) road section as a function of instruction, lane width (wide = 2.75 m, narrow = 2.25 m), and edge strip configuration.



Repetition appears to have a main effect on speed (F2,56)=38.3, p<0.0001). Speed increases with repetition, but the speed on the narrow lanes increases relatively the least (interaction lane width x repetition F(2,56)=7.5, p<0.002), see Fig. 2.

By analyzing the difference between the speed on an experimental road and the control road section within the same block, the effect of repetition can be compensated for. Then, an ANOVA reveals a main effect of lane width (F(1,28)=40.2, P<0.0001). The narrow lane gives the highest speed reduction. Combined with the narrow lane, the edge strip configuration with the continuous profiled marking reduces speed more than the 5 or 10 m rumble (interaction lane width x configuration F(2,56)=7.5, p<0.002).

Figure 2: Mean speed of on straight (left) and curved (right) road sections as a function of repetition, control section and lane width.



Lateral placement

For each subject the average lateral position relative to the centre of the road has been calculated for both straight and curved road sections. ANOVAs reveal that neither repetition, instruction, or edge strip configuration has an effect on lateral position. As can be expected lane width has far the greatest effect on lateral position ($F(1,28)=509$, $p<0.0001$). In the wide lane one drives 1.22 m from the middle of the road, whereas the narrow lane results in a lateral position of 0.99 m, compared with 1.08 m in the control condition (straight road sections). The lane keeping behaviour for both lane widths differs significantly from that in the control condition (mean lateral position 1.18 m) (wide lane vs. control, $t=4.04$, $p<0.001$; narrow lane vs. control, $t=2.58$, $P<0.02$).

The s.d. of lateral position is independent of repetition, instruction, and edge strip configuration. Compared with the control condition, the experimental lanes reduce the s.d. of lateral position ($F(3,84)=52.4$, $p<0.0001$) with the narrow lane having the strongest effect (s.d. lateral position on straight road sections on control, wide lane and narrow lane 0.18, 0.15, and 0.12 m, respectively). In the narrow lane condition drivers steer more accurately.

4. Implementation on the road

The results of the simulator study show that the narrow lane width (2.25 m + 0.70 m edge strip) gives the largest speed reductions and is fairly resistent to effects of adaptation. Moreover, the narrow lane width especially reduces the speeds of drivers under time-pressure, implying that also in practice speed variance may be reduced. The different lay-outs of the edge strips reveal relatively small differences in driving behaviour. The basic design elements as developed in this project offer a good prospect for reducing driving speeds in practice. To optimise the final physical characteristics of the edge strip mathematical computer simulations have been conducted (Hoogvelt & Jansen, 1992). These simulations resulted in an edge strip of 4 m long blocks of chippings with a spacing of 4 m. Together with the reduced lane width of smooth asphalt of 2.25 m and a 0.30 m central chipping strip marking, the removal of the white edge lines and post-mounted reflectors on straight road sections, this basic design package of speed reducing measures was tested on four experimental road sections in Drenthe, see Fig. 3. This package of measures was expected to be effective at reasonable costs, maintenance friendly, and in case of failure relatively easy to remove again.

Figure 3: Basic design package of speed-reducing measure as tested in Drenthe.

4.1 Speed measurements

At the four experimental road sections and at five comparable control sections speed measurements with inductive loop detectors have been conducted for a period of in total over two years (Steyvers, 1995). After a before measurement, at each location speeds have been measured quarterly during a period of four weeks, 24 hours a day. The effect of the speed-reducing measures after one year appeared to be about 2.1 km/h, as an average over all experimental locations in comparison with the control locations. After the second year the effect was reduced till about 1.7 km/h, on average. In the same period, some physical wear of the chipped edge strips was noted with, as a result, a reduction in discomfort (Laméris, 1994).

4.2 Lateral placement

From the results of the simulator study some concerns existed with respect to the lateral placement of drivers due to the physical measures. Would drivers choose a lateral position in the traffic lane closer to the middle of the road with, as a consequence, a higher risk on head-on collisions? To quantify the effects of the measures on the lateral placement of vehicles, the driving behaviour at one experimental location was compared with that at a conventional 80 km/h road (lane width 2.75 m, and standard road delineation of a 0.10 m centre and edge lines) by means of a quantitative analysis of video recordings (van der Horst & Bakker, 1994). The analysis of cumulative distributions of the lateral placement of free-driving vehicles (both passenger cars and trucks) at both sites reveals that the package of speed-reducing measures does <u>not</u> result in a lateral placement more to the middle of the road. In contrary, the 0.30 m central chipping strip marking (instead of the 0.10 m conventional central marking) even results in a lateral placement of minimally 0.10 m more away from the centre of the road, see Fig. 4. Drivers mainly seem to refer to the most near-by side of the central marking. At the moment on-coming traffic is passing, the lateral placement is not influenced at all by the measures. Apparently when passing, drivers orientate completely on the other vehicle, the mutual distance between two passing vehicles does not differ at all between the experimental and control location, see Fig. 5.

Figure 4: Cumulative distributions of lateral placement of the left (LW) and right (RW) wheel of free-driving passenger cars at the experimental and control location, relative to the middle of the road (0 cm).

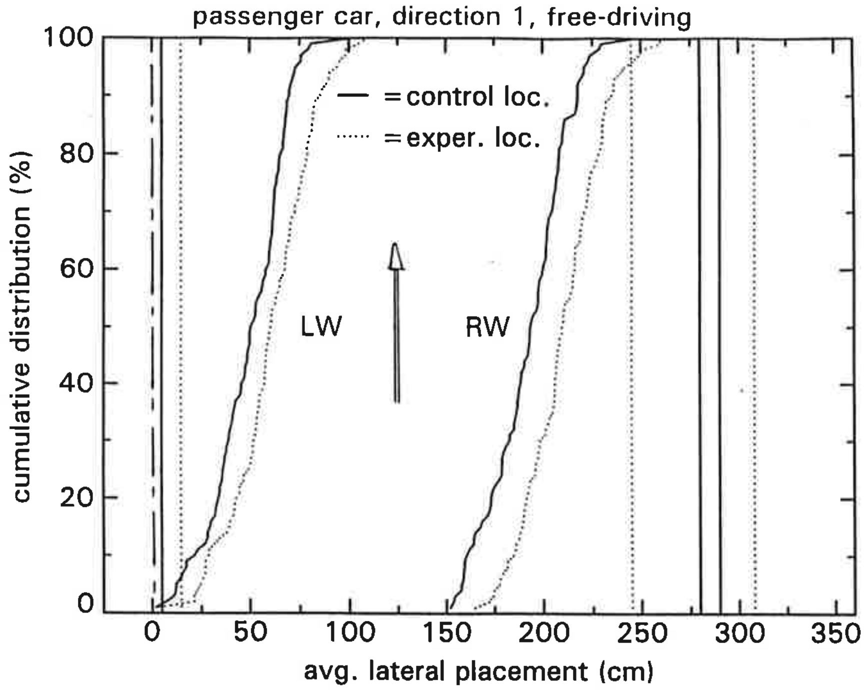
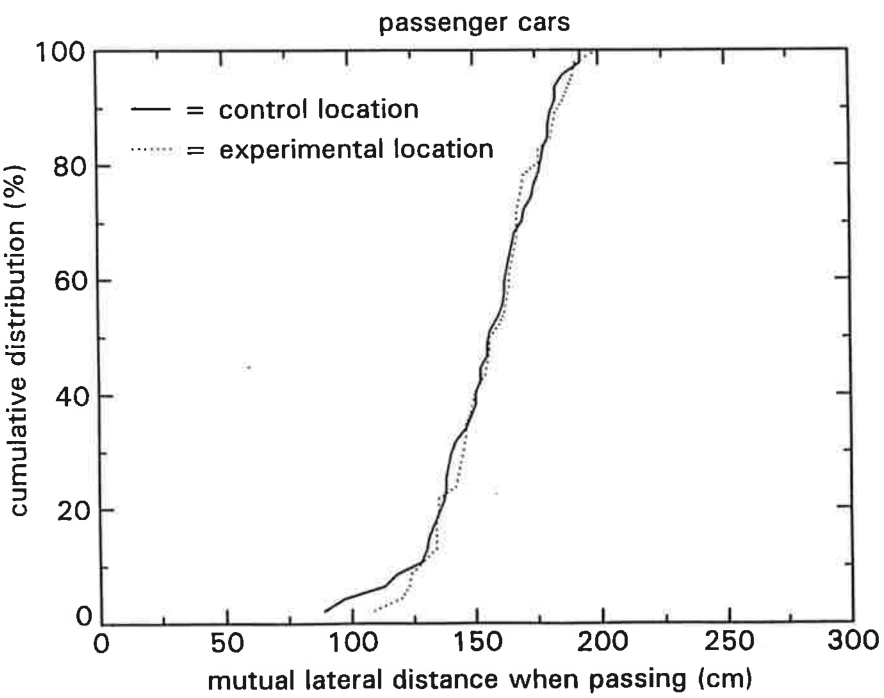


Figure 5: Cumulative distributions of the mutual distance between passenger cars at the moment of passing at the experimental and control location.



4.3 Accidents

An analysis of all police-reported accidents at the experimental locations and at the control locations for a two-year period before-and-after implementation of the measures reveals a 20% reduction of the number of accidents (from 80 to 64) at the experimental road sections, while an 8% increase occurred at the control locations (from 119 to 129). The number of people injured at the experimental locations is reduced with 36% (from 28 to 18), while at the control locations an increase with 17% (from 41 to 48) was observed.

5. Conclusions

The experimental project "Speed-reducing measures 80 km/h roads in Drenthe" is a good example of an approach where in an early stage of the design process knowledge and know-how of various disciplines has been included. Human factors knowledge based on behavioural research has contributed substantially to the development of the resulting basic design package for 80 km/h roads. Based on a driving simulatorstudy, it was concluded that the basic design elements as proposed in this project offer a good prospective for reducing driving speeds successfully in practice. A narrow lane width of "smooth" asphalt of 2.25 m together with an edge strip of 0.70 m and a centre marking of 0.30 m, both with acoustic feed-back to the driver when crossing, appears to be an effective set of measures to reduce speed. A thorough evaluation of actual driving speeds on four experimental road sections, based upon the analysis of inductive loop data of a two-year period, a sustainable speed reduction of about 2 km/h could be achieved. In spite of a reduced lane of smooth asphalt and a discomfort edge strip, a 0.30 m central chipping strip marking results in a 0.10 m lateral placement shift away from the centre of the road. Apparently, drivers mainly focuss on the near-by side of the central marking. A two year before-and-after comparison of accident statistics reveals a positive effect on road safety of the speed-reducing measures, as implemented on 80 km/h roads in Drenthe.

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REFERENCES

HEIDEMIJ (1992), Proefproject snelheidsbeperkende maatregelen op 80 km-wegen: Schetsboek basisontwerp 80 km-wegen (Pilot project speed-reducing measures on 80 km/h roads: sketch book basic design 80 km/h roads). Assen: Heidemij Advies bv.

HOEKSTRA W., HORST A.R.A. van der & KAPTEIN N.A. (1997), Visualisation of road designs for assessing human factors aspects in a driving simulator. Proceedings Driving Simulator Conference '97, September 8-9, 1997, Lyon.

HOOGVELT R.B.J. & JANSEN S.T.H. (1992), Oneffenheden in de kantstrook van 80 km/h wegen in Drenthe als fysieke maatregel om de rij-snelheid te beperken (Road-edge unevenness patterns on 80 km/h roads in Drenthe as a physical measure to reduce driving speed). (Report 92.RAS.81.1/BH). Delft: Road-Vehicles Research Institute.

HORST A.R.A. van der & BAKKER P.J. (1994), Effecten van snelheidsbeperkende maatregelen op 80-km wegen in Drenthe op de dwarspositie van voertuigen (Effects of speed-reducing measures at 80 km/h roads in Drenthe on lateral placement of vehicles). (Report TNO-TM 1994 C-25). Soesterberg: TNO Human Factors Research Institute.

HORST A.R.A. van der & HOEKSTRA W. (1994), Testing Speed Reduction Designs for 80 Kilometer per Hour Roads with Simulator. Transportation Research Record 1464. Washington, D.C.: Transportation Research Board, 63-68.

HORST A.R.A. van der & HOEKSTRA W. (1992). Effecten van snelheidsbeperkende maatregelen op 80 km-wegen Drenthe op het rijgedrag: Een Simulatorstudie (Effects of speed-reducing measures at 80 km/h roads Drenthe on driving behaviour: a simulator study). (Report IZF 1992 C-30). Soesterberg: TNO Human Factors Research Institute.

HORST A.R.A. van der, JANSSEN W.H. & KORTELING J.E. (1991), Measuring Effects of Variable Message Signing on Route-Choice and Driving Behaviour. In: Proc. SHRP Conference, Gothenburg, Sweden, Sept. 18-20, 1991. VTI Rapport 372A, part 1. Swedish Road and Traffic Research Institute, Linköping, pp. 75-84.

KOORNSTRA M.J., MATHIJSSEN M.P.M., MULDER J.A.G., ROSZBACH R. & WEGMAN F.C.M. (1992), Naar een duurzaam veilig wegverkeer: Nationale Verkeersveiligheidsverkenning voor de jaren 1990/2010 (Towards a sustainable safe road traffic: A national traffic safety exploration). Leidschendam: Road Traffic Safety Research Institute.

LAMÉRIS F.W. (1994), Comfortmetingen op 80 km/uur wegen op vier locaties in de provincie Drenthe (Comfort measurements on 80 km/h roads at four locations in the province of Drenthe). (Report 94.mr.vd.059.1/FL). Delft: TNO Road-Vehicles Research Institute.

RIEMERSMA J.B.J., HOEKSTRA W., HORST A.R.A. van der, ALINK G.M.M. & OTTEN N. (1990), The validity of a driving simulator in evaluating speed reducing measures. Traffic Engineering + Control, Vol. 31, No.7, pp. 416-420.

STEYVERS F.J.J.M. (1995), Snelheidsmetingen in het project Snelheidsbeperkende maatregelen op 80 km/h wegen in Drenthe: eindrapport (Speed measurements for the project Speed-reducing measures on 80 km/h/ roads in Drenthe: final report). (Report VK 95-05) Haren: Traffic Research Centre, Groningen University.

TENKINK E. & Horst A.R.A. van der (1991), Effecten van wegbreedte en boogkenmerken op de rijsnelheid (Effects of road-width and curvature characteristics on driving speed). (Report IZF 1991 C-26). Soesterberg: TNO Human Factors Research Institute.

TENKINK E. (1990), Effecten van wegbreedte en een additionele taak op rijsnelheid en koersgedrag. (Effect of road width and an additional task on speeds and lateral control). (Report IZF 1990 C-27). Soesterberg: TNO Human Factors Research Institute.

TENKINK E. (1989), De invloed van wegbreedte en obstakeldreiging op snelheids- en koersgedrag (The influence of road width and obstacle-threat on speed and lateral placement behaviour). (Report IZF 1989 C-4). Soesterberg: TNO Humena Factors Research Institute.

TENKINK E. (1988), Determinanten van rijsnelheid (Determinants of driving speed). (Report IZF 1988 C-3). Soesterberg: TNO Human Factors Research Institute.

THEEUWES J. & GODTHELP J. (1992), Begrijpelijkheid van de weg (Self-explaining roads). (Report IZF 1992 C-8), Soesterberg: TNO Human Factors Research Institute.

HOW TO EVALUATE THE SAFETY ASPECTS OF DAYTIME RUNNING LIGHTS, Wolf Dietrich Zuzan

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1. Introduction

It's nearly 10 years ago that the Austrian Road Safety Board started with studying the safety effects of DRL and began to promote that measure in the public. Daytime running light (DRL) means at the moment to drive with dipped (head) lights (50 W) but in the future there should be a special light connected with the ignition system with 20 W lights. At the moment runs a campaign of the federal ministry for science and traffic in the Austrian radio and television under the title „Drivers with light are more bright" (Lichtfahrer sind sichtbarer).

Original the Austrian government - a coalition of socialists (SPÖ) and Christian conservatives (ÖVP) - intended to carry out a two years experiment to evaluate the safety effects of DRL in Austria, because one main counter argument was that it works in the surroundings and conditions in Sweden but never in Austria. The political discussion in the media and in circles does not accept the relevance of foreign experiments with DRL. Therefore arises the question if it is possible to prove the relevance of earlier evaluation studies for Austria. So it is an important question to determine exactly the effects of DRL in Austria. Meanwhile the political discussion does not get ahead and the Christian conservative party (ÖVP) refuses the implementation even of a great experiment to prove the effects of DRL.

The original plan was that in the first year of experiment DRL will only be advertised. This part was in fact carried out by the mentioned advertising campaign „drivers with light are more bright". There will be no surveillance and no punishment of drivers not having the lights on during daytime. Only in the second year of the experiment drivers of „dark" cars have to pay a fine of 200 ATS (it is approx. 17 US$) if they are stopped for a routine control or for a check caused by other violations. No car should be checked only due to the fact that the car has no lights on at daytime. By that control of DRL will be minimalized. So you can not assume a high rate of participation. To my mind in the first year the participation rate will not exceed 30 % in general and in the second year of experiment it will be at about 50% at the maximum. The safety effects therefore will not be identical to the target situation with 100% showing DRL! There will be in traffic a mixture of cars with the lights on and of cars without lights. That gives on the one hand the risk to overlook a car but on the other hand by applying of Humphry's Paradox there could be also the best safety effect due to the conscious risk to miss a „dark" car. The tension of expectation achieves its maximum.

2. The design of former experiments

Hansen Lars Klit (1994) described the experience with compulsory use of the DRL in Denmark. DRL (dipped light or special running lights) got compulsory for all motor vehicles during daytime by October 1st, 1990. When DRL were introduced, the rules for carrying headlights at night were adjusted that the minimum lights at nighttime were dipped lights.

To evaluate the impact of DRL on accidents the development of accidents with personal damage has been studied 15 three-months periods before the introduction (i.e. since 1987) and 11 three-months periods after (until 1993). During that period there were only few law amendments which might have affected daytime accidents except of an increased enforcement of drunk driving. Therefore accidents with drunk drivers where excluded from the evaluation study. For the remaining groups of accidents a statistical analysis has been made in order to calculate an „expected" number of accidents. A log-linear model has been used.

Accidents between two cars and single vehicle accidents were divided into nine main accident situations. Accidents at daylight and during darkness were separately calculated and compared. In the first evaluation it was concluded that the effect was concentrated only on the accident situation left turn in front of an oncoming vehicle. The accident reduction was estimated to 37 %. In fact the change was about 34%! During darkness left-turn accidents raised by 6%!

As a control group the single car accidents were used: for single vehicle accidents an increase of 9% was found for daylight accidents and a decrease of 13% in darkness. So the effect could be ensured by two different measures: the same type of accident in two different conditions (day vs. night) and two different types of accidents (left-turn vs. single car) whereby one type (single car) could not really be influenced by DRL.

Elvik Rune (1993) reported on the effects on accidents of compulsory use of daytime running lights for cars in Norway. The use of DRL were made mandatory for all cars from April 1st, 1988. From January 1st, 1985 DRL switched on by the ignition were required for all new cars.

His study design is a non-experimental before and after study and covers the years from 1980 to 1990. The year 1980 was chosen due to three reasons: it is the first year for which estimate of the use of DRL are available. Second, summertime was introduced in Norway this year. Third, there have been no major changes in legislation concerning accident reporting after 1980. The years 1980 to 1984 constitute the before period and the years 1985 to 1990 constitute the after period divided in due sub-periods due to the fact the DRL have got mandatory after April 1st, 1988.

Only multiparty accidents in daylight are assumed to be influenced by DRL. The other types of accidents are assumed not to be influenced by the use of DRL and constitute the comparison group. All motorcycle accidents were excluded because DRL have got compulsory for motorcycles already 1978. Accidents with personal damage were used only and broken down by light condition in daylight, twilight and darkness. Daylight multiparty car accidents are further broken down into by time of year (summer, winter) road environment (town, countryside) and type of accident (pedestrian, rear end, head on, turning, right angle and others).

Now a criterion of effectiveness was calculated relating the quotients of multiparty to single car accidents under daylight conditions to the quotient of these accidents at night. The validity of using changes in the odds ratio as criteria of effectiveness rests on the validity of the ceteris paribus clause it relies on. Generally the odds ratio does not take account of changes that effect one of the four types of accidents that enter into its calculation selectively. If other effects are present in the data the effect of DRL can be falsely reinforced or hidden. An increasing number of single car accidents my generate a false impression of an effect of DRL or falsely reinforce a true effect. By that it seems to me this evaluation criterion is problematic.

We saw in the study of Lars Klit Hansen (1994) that not all types of multiparty accidents are influenced in the same amount by DRL. If you do not regard these effects DRL effects might be masked.

But Elvik Rune (1993) emphasizes correctly the importance of study design (Company fleet experiment versus nationwide because in the first case you might have a DRL rate of 5% in the whole traffic and in the other case 90%) stresses the weakness of accident data (only one of three injury accidents is actually reported to the police and so included in official statistics) and formulates clear hypothesis (e.g. that the use of DRL has no effect on the number of daylight rear-end collisions). He discusses finally confounding factors like changes in vehicle speed, extension of road lightning, changes in DWI driving and so on.

Arora H., Collard D., Robbins G., Welbourne E.R. and White J.G. (1994) studied the effectiveness of DRL in Canada. Canada Motor Vehicle Safety Standard 108 requires that DRL be installed on all new cars, trucks, busses etc. after December 1st, 1989. Collisions of all severities corresponding to four accident types were extracted from the national Traffic Accident Information Data base (TRAID) for calendar years 1984 to 1991. The target group was defined as two-vehicle different direction daytime collision compared with single vehicle daytime collisions. Additional comparisons were made with two vehicle different direction nighttime collisions and single vehicle nighttime collisions like in the study of Hansen Lars Klit (1994). An odds ratio of target group collisions to the comparison groups collisions was calculated like in the study of Elvik Rune (1993) but not for all multiparty accidents together. The odds ratio was calculated for each of five late model vehicle collisions totals in each calendar year because equipment with DRL has got mandatory only for new cars. The odds ratio for a given model year was then compared with the odds ratio for the previous model year and tested with chi-squared test of significance.

Lindeijer J.E. (1991) designed a masterplan for an evaluation study into the effect of DRL on road safety in the Benelux-countries. He criticizes that national evaluation studies gave little attention to exposure or to development in driving performance and mobility in traffic. He calls for an exact estimation of the use of DRL and to control all other conditions influencing accident occurrence at the same time. He demands that the difference in the use of DRL when comparing the before and after period must be sufficient. But it is not correct to assume that the effect of DRL rises linearly from 0 to 100%. In the contrary it might be possible that the accident preventing effect is on top at 50% usage of DRL.

3. The proposed experimental design of the Austrian DRL evaluation study

To measure the effects of DRL the accident figures in the two years before start of the experiment and during the experiment endurance (2 years) should be compared and analyzed. Basis for the analysis of accident occurrence are the accident data reported by the Austrian board on statistic, a federal office. By that only accidents with personal damage will be reported. The federal ministry for science and transport will invite tenders for the performance of the accident research and the accident analysis through an official or private institute.

The aim of the investigation will be the exact representation of accident occurrence - e.g. the accidents with personal damage - in the period two years before the introduction of DRL and during the two years of implementation of DRL. The results of the first year of experiment have to be presented six months after the end of the first year of performance of DRL as an intermediate report and the final report has to be presented six months after the second year of experiment. The reports should show the trend of accident figures during the experiment in comparison with the accidents in the two years before. The statements to the analysis of accident figures have to refer to the determined rates of application of DRL that means the percentage of cars having the lights on during daytime. These rates will be determined not only for the whole state but also for regions. The accident figures therefore have to refer also to these regional data.

To determine the effects of DRL only those accidents should be taken for evaluation where both partners used DRL. All other accidents should count for the control group.

Accidents assumed referring to DRL are:

Superior group 1: accidents with traffic in the same direction

sub group 12: collision during change of lanes

sub group 13: rear-end collisions to driving vehicle

sub group 14: rear-end collisions to standing vehicles

sub group 15: rear-end collisions at crossings to driving vehicle

sub group 16: rear-end collisions at crossings to standing vehicle

Superior group 2: accidents with oncoming traffic

Superior group 4: accidents during branch off - opposite direction

sub groups 41, 42, 43: collisions during branch off on crossings

Superior group 5: right angle collisions on crossings

right angle collisions while turning in

sub group 8: pedestrian accidents

sub group 9: accidents in entrances or doorways

sub group 94: collisions at entrances or doorways

But the cited studies show that DRL influence rear-end collisions in an other way them accidents during branch off. By that effects of DRL could be masked. Better the analyzis should be carried out for each type of accident separately.

The control group beyond it will be constituted by the following types of accidents:

- single car accidents
- night time accidents in general
- all other accidents not related to DRL

Nevertheless the police have to know whether or not a car involved in an accident had the lights on or not in the accidental situation. By that it would be possible to compare accidents as follows:

- light to light
- light to dark
- dark to dark
-

By political decision the design has been restricted to a pre-after design of comparison of accident data. Conflict studies and driver interviews were excluded. This restriction in connection with the expected low application rate of DRL hinders the evaluation of DRL in Austria.

The following aspects should be studied:

- evaluation separated for the different types of roads e.g. freeway, federal highway, regional roads, community roads, traffic in towns and outside towns
- evaluation separated for the different parts of the control group e.g. accidents with more than two partners involved at night, single car accidents during night and at daylight accidents with no relevance to DRL during daytime and accidents in principle relevant for DRL but not all partners showing DRL
- evaluation according to the light situation that means: blinding sun, daylight in comparison with dawn, twilight and artificial lightning.

Due to the fact that all these variables are not clearly separated but in some way interfered multivariate analysis will be needed.

4. *Special hypothesis and remarks*

Masking effects could emerge by changements in the general development of traffic safety in Austria and in Europe and there are such changes by the introduction of probatory license, the introduction of a point demerate system, less young drivers because their percentage in the population is continuously decreasing with increasing motorization.

Other effects depend from changements in licensing like moped riding with 15, C-1 license, changes in driver education and driver testing. Further problems arise from changes in the value system of the entire society - e.g. if you compare the 68-generation with today's students. And there are changes in the population by continuing immigration from Asia, Africa and Eastern European countries. Nevertheless the percentage of female drivers rises quickly. ...

REFERENCES

ARORA H., COLLARD D., ROBBINS G. WELBOURNE E.R. and WHITE J.G. (1994), Effectiveness of Daytime Running Lights in Canada. Transport Canada Publication Nr. TP 12298 (E), Ottawa

ELVIK RUNE (1993), The Effects on Accidents of Compulsory Use of Daytime Running Lights for Cars in Norway. Accident Analysis and Prevention, Vol. 25, No. 4, pp 383-398.

HANSEN LARS KLIT (1994), Daytime Running Lights (DRL): Experience with Compulsory Use in Denmark. Danish Council of Road Safety Research, Copenhagen.

KOORNSTRA M.J., MATHIJSSEN M.P.M., MULDER J.A.G., ROSZBACH R. & WEGMAN F.C.M. (1992), Naar een duurzaam veilig wegverkeer: Nationale Verkeersveiligheidsverkenning voor de jaren 1990/2010 (Towards a sustainable safe road traffic: A national traffic safety exploration). Leidschendam: Road Traffic Safety Research Institute.

KURATORIUM FÜR VERKEHRSSICHERHEIT (1996), Entwicklung des Personenschadenunfallgeschehens auf Österreichs Straßen im Rahmen des Großversuches „Fahren mit Licht am Tag". Diskussionsvorschlag IVU, Wien

LINDEIJER J.E. (1991), Benelux Test with Daytime Running Lights (DRL). SWOV Institute for Road Safety Research, Leidschendam, NL

LIST OF REFERENCES

ARORA H., COLLARD D., ROBBINS G. WELBOURNE E.R. and WHITE J.G. (1994), Effectiveness of Daytime Running Lights in Canada. Transport Canada Publication Nr. TP 12298 (E), Ottawa

BOX G.E.P., TIAO G.C. (1972), Bayesian inference in statistical analysis. Addison-Wesley Publishing Company, Reading. 588 p.

BUNN D.W. (1984), Applied decision analysis. McGraw-Hill Book Company, New York. 251 p.

COOKE R.M. (1991), Experts in uncertainty: Expert opinion and subjective probability in science. Oxford University Press, New York. 321 p.

DEUTSCHER VERKEHRSSICHERHEITS-RAT DVR (1992), Unfallverhütungsbericht Straßenverkehr 1991. Bericht des Bundesministers für Verkehr über Maßnahmen auf dem Gebiet der Unfallverhütung im Straßenverkehr für die Jahre 1990 und 1991; Übersicht Rettungswesen, DVR Drucksache 12/3102

ELVIK RUNE (1993), The Effects on Accidents of Compulsory Use of Daytime Running Lights for Cars in Norway. Accident Analysis and Prevention, Vol. 25, No. 4, pp 383-398.

EVANS A. (1994), The Evaluation of Public Transport Safety Measures, Public Transport International, 3-1994, pp 32-35

GLEDEC M. (adopted 1986, revised 1992), Zagreb Master Plan

GLEDEC M., EVANS A. (1994), The Evaluation of Public Transport Safety Measures, Public Transport International, 3-1994, pp 32-35,

GLEDEC M. (1995), Zagreb Statistical Yearbook

GLEDEC M. (1995), The Police Bulletin on the traffic safety in City of Zagreb

HANSEN LARS KLIT (1994), Daytime Running Lights (DRL): Experience with Compulsory Use in Denmark. Danish Council of Road Safety Research, Copenhagen.

HEIDEMIJ (1992), Proefproject snelheidsbeperkende maatregelen op 80 km-wegen: Schetsboek basisontwerp 80 km-wegen (Pilot project speed-reducing measures on 80 km/h roads: sketch book basic design 80 km/h roads). Assen: Heidemij Advies bv.

HOEKSTRA W., HORST A.R.A. van der & KAPTEIN N.A. (1997), Visualisation of road designs for assessing human factors aspects in a driving simulator. Proceedings Driving Simulator Conference '97, September 8-9, 1997, Lyon.

HOOGVELT R.B.J. & JANSEN S.T.H. (1992), Oneffenheden in de kantstrook van 80 km/h wegen in Drenthe als fysieke maatregel om de rij-snelheid te beperken (Road-edge unevenness patterns on 80 km/h roads in Drenthe as a physical measure to reduce driving speed). (Report 92.RAS.81.1/BH). Delft: Road-Vehicles Research Institute.

HORST A.R.A. van der & BAKKER P.J. (1994), Effecten van snelheidsbeperkende maatregelen op 80-km wegen in Drenthe op de dwarspositie van voertuigen (Effects of speed-reducing measures at 80 km/h roads in Drenthe on lateral placement of vehicles). (Report TNO-TM 1994 C-25). Soesterberg: TNO Human Factors Research Institute.

HORST A.R.A. van der & HOEKSTRA W. (1994), Testing Speed Reduction Designs for 80 Kilometer per Hour Roads with Simulator. Transportation Research Record 1464. Washington, D.C.: Transportation Research Board, 63-68.

HORST A.R.A. van der & HOEKSTRA W. (1992). Effecten van snelheidsbeperkende maatregelen op 80 km-wegen Drenthe op het rijgedrag: Een Simulatorstudie (Effects of speed-reducing measures at 80 km/h roads Drenthe on driving behaviour: a simulator study). (Report IZF 1992 C-30). Soesterberg: TNO Human Factors Research Institute.

HORST A.R.A. van der, JANSSEN W.H. & KORTELING J.E. (1991), Measuring Effects of Variable Message Signing on Route-Choice and Driving Behaviour. In: Proc. SHRP Conference, Gothenburg, Sweden, Sept. 18-20, 1991. VTI Rapport 372A, part 1. Swedish Road and Traffic Research Institute, Linköping, pp. 75-84.

KOORNSTRA M.J., MATHIJSSEN M.P.M., MULDER J.A.G., ROSZBACH R. & WEGMAN F.C.M. (1992), Naar een duurzaam veilig wegverkeer: Nationale Verkeersveiligheidsverkenning voor de jaren 1990/2010 (Towards a sustainable safe road traffic: A national traffic safety exploration). Leidschendam: Road Traffic Safety Research Institute.

KURATORIUM FÜR VERKEHRSSICHERHEIT (1996), Entwicklung des Personenschadenunfallgeschehens auf Österreichs Straßen im Rahmen des Großversuches „Fahren mit Licht am Tag“. Diskussionsvorschlag IVU, Wien

LAMÉRIS F.W. (1994), Comfortmetingen op 80 km/uur wegen op vier locaties in de provincie Drenthe (Comfort measurements on 80 km/h roads at four locations in the province of Drenthe). (Report 94.mr.vd.059.1/FL). Delft: TNO Road-Vehicles Research Institute.

LINDEIJER J.E. (1991), Benelux Test with Daytime Running Lights (DRL). SWOV Institute for Road Safety Research, Leidschendam, NL

LIPPHARD D. (1994), Geschwindigkeiten in den neuen Bundesländern - Verhaltensänderungen 1991-1993. Neue Fahrbahnen, Ausstattung, Umfeld, ZVS 40, 4/IV

LIU Y. (1996), Vergleich der Straßenverkehrssicherheit zwischen der Volksrepublik China und der alten Bundesrepublik Deutschland, ZVS 40, 4/IV

MAYBECK P.S. (1979), Stochastic models, estimation and control. Vols. 1-2. Academic Press, New York. 423+289 p.

McCORMICK N.M. (1981), Reliability and risk analysis. Methods and nuclear power applications. Academic Press, New York. 446 p.

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. (1994), Statistical models for expert judgement and wear prediction. VTT Publications 181. Technical Research Centre of Finland, Espoo. 65 p. + app. 80 p.

REKER K., BUSS E. & ZWIELICH F. (1993), Fahrverhaltensbeobachtung im Raum Berlin, Berichte der Bundesanstalt für Straßenwesen

RIEMERSMA J.B.J., HOEKSTRA W., HORST A.R.A. van der, ALINK G.M.M. & OTTEN N. (1990), The validity of a driving simulator in evaluating speed reducing measures. Traffic Engineering + Control, Vol. 31, No.7, pp. 416-420.

SARTRE (1994), Social Attitudes to Road Traffic Risk in Europe. European Drivers and Traffic Safety, Presses Ponts et Chaussées

SCHULZE H. (1996), Lebensstil und Verkehrsverhalten junger Fahrer und Fahrerinnen, Berichte der Bundesanstalt für Straßenwesen (BASt), Heft 56

STEYVERS F.J.J.M. (1995), Snelheidsmetingen in het project Snelheidsbeperkende maatregelen op 80 km/h wegen in Drenthe: eindrapport (Speed measurements for the project Speed-reducing measures on 80 km/h/ roads in Drenthe: final report). (Report VK 95-05) Haren: Traffic Research Centre, Groningen University.

TENKINK E. & Horst A.R.A. van der (1991), Effecten van wegbreedte en boogkenmerken op de rijsnelheid (Effects of road-width and curvature characteristics on driving speed). (Report IZF 1991 C-26). Soesterberg: TNO Human Factors Research Institute.

TENKINK E. (1990), Effecten van wegbreedte en een additionele taak op rijsnelheid en koersgedrag. (Effect of road width and an additional task on speeds and lateral control). (Report IZF 1990 C-27). Soesterberg: TNO Human Factors Research Institute.

TENKINK E. (1989), De invloed van wegbreedte en obstakeldreiging op snelheids- en koersgedrag (The influence of road width and obstacle-threat on speed and lateral placement behaviour). (Report IZF 1989 C-4). Soesterberg: TNO Humena Factors Research Institute.

TENKINK E. (1988), Determinanten van rijsnelheid (Determinants of driving speed). (Report IZF 1988 C-3). Soesterberg: TNO Human Factors Research Institute.

THEEUWES J. & GODTHELP J. (1992), Begrijpelijkheid van de weg (Self-explaining roads). (Report IZF 1992 C-8), Soesterberg: TNO Human Factors Research Institute.

THE POLICE BULLETIN on the traffic safety in City of Zabreb (1995)

ZAGREB MASTER PLAN, adopted 1986, revised 1992

ZABREB STATISTICAL YEARBOOK (1995)