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PEDESTRIAN SAFETY AT TRAFFIC SIGNALS: A STUDY CARRIED OUT WITH THE HELP OF A TRAFFIC CONFLICTS TECHNIQUE

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Abstract—Most pedestrian accidents in built-up areas occur at intersections. Even after signalization the number of accidents involving pedestrians often remains high. After reviewing the published evidence, this paper describes how the Traffic Conflicts Techniques has been used to examine the risk to pedestrians at 120 intersections. The principal results indicate that signalization of a high-speed intersection (mean speed above 30 km/h in at least one arm) reduces pedestrian risk to approximately half. If mean speed in every arm is below 30 km/h signalization also reduces pedestrian risk, as long as most vehicles are not turning. Another finding from these studies was that a crosswalk should be located less than two meters from the intersection to optimize pedestrian safety. The conflict studies as well as analyses of accident data show that one should examine separately accidents between turning vehicles and "green-walking" pedestrians and accidents involving pedestrians walking against red light. The effect of an exclusive pedestrian signal phase (scramble) was tested at three sites and proved to be very safety-beneficial in a small town, while in Stockholm it did not prove effective because of a high percentage of red-walkers. Vehicle delay, as well as pedestrian delay, increased at all three sites. Data collected at 152 crosswalks has been used to estimate the parameters of a multivariate model of the frequency of "red-walking." The size of the town and traffic volumes appear to be the major factors influencing this frequency. Additional insight has been obtained from personal interviews of 450 persons. These indicate that shorter waiting times and police enforcement are considered the most efficient measures to reduce the the frequency of red-walking.

1. INTRODUCTION

Pedestrian accidents account for a large portion of the injury accidents in most countries. In Sweden, for example, almost every fourth traffic fatality is a pedestrian (Trafiksäkerhetsverket 1987). Out of all pedestrian accidents in Sweden, 75% happen in built-up areas. Among these, about 80% occur in at intersections. Signalization is perhaps one way to increase the safety of pedestrians at intersections.

The purpose of this study has been to investigate the effect of signalization on pedestrian safety, to analyze the causes of pedestrian accidents at signalized intersections, and to identify measures that can reduce risk to pedestrians at signalized intersections.

In Section 2 we briefly review the published evidence. This is followed in Section 3 by an exploratory analysis of pedestrian accidents at 34 signalized intersections in Sweden. After these preliminaries, we turn to the task of examining the effect of signalization on accident risk. Following a brief review of the Traffic Conflicts Technique (TCT) (Section 4), we present the main results in Section 5. Risk to pedestrians is assessed at signalized vs. unsignalized intersections, and its dependence on approach speed, presence of refuge, and other factors is examined. In Section 6 we examine the safety consequences of an exclusive pedestrian phase (scramble) at signalized intersections and in Section 7 we examine, within the framework of a multivariate model, what affects the proportion of "red-walking" pedestrians. Our principal conclusions are given in Section 8.

2. REVIEW OF PUBLISHED EVIDENCE

Studies of research material show a great variation in the effect of signalization on pedestrian safety. Jörgensen and Rabani (1971), as well as Older and Grayson (1976), show that there are more pedestrian accidents per passage at nonsignalized than signalized intersections (two to five times as many). A study by Kraay, Slop, and Oppe (1974) shows that the difference in risk between signalized and nonsignalized intersections is greater in Holland and Germany than in England and Denmark, probably because of differences in legislation and pedestrian behavior. In England, for example, pedestrians are normally given absolute priority over vehicles at nonsignalized crosswalks. This is not the case in most other European countries.

In the studies mentioned above it is possible that other factors than the signal have influenced the results. It is perhaps better to establish the effect of signalization by "before-and-after" studies. Two such studies are outlined below.

The first study is Swedish (Bång 1969). In Stockholm, 12 intersections were signalized. After signalization the number of pedestrian accidents increased from 7 to 15 (not a statistically significant change).

The second study is American (Short, Woelfl, and Chang 1982). Here, accident data from 31 intersections were analysed. After correcting for a 5% change in traffic volumes, the following results were obtained. In total, the number of accidents decreased from 533 to 522 for identical time periods. There was no statistically significant change in the number of pedestrian accidents (from 19 to 12).

The main conclusion from the above studies is that the effect of signalization on pedestrian safety seems to vary. An obvious reason for variations in the effect can be the degree of "red-walking." The number of accidents with red-walkers ought to depend mostly on the number of red-walkers. An Australian study (Cameron, Stanton, and Milne 1976) shows that the risk is about 20 times greater for a red-walker than for a green-walker.

3. EXPLORATORY ACCIDENT ANALYSIS

Seven years of accident data was analyzed from 22 signalized intersections in Stockholm (metropolitan population 1.3 million) and 12 in Malmoe (population 240,000). As can be seen in Tables 1 and 2 there are three prevalent types of accidents involving pedestrians:

(i) turning vehicles vs. pedestrians walking with the green light,
(ii) red-walking pedestrians vs. green-driving vehicles, and
(iii) red-driving vehicles vs. green-walking pedestrians.

The results show that of the pedestrian accidents at signalized intersections, a turning car was involved in 39% in Stockholm and in 47% in Malmoe. Red-walking counted for 50% and 41%, respectively, while red-driving counted for the rest, i.e. 13% and 12% respectively. Right turn on red is neither legal nor practiced in Sweden.

Turning vehicles and red-walking seem to be the most common types of accidents. It is, therefore, reasonable to assume that the effectiveness of signalization mostly depends on how the conflicts between turing vehicles and pedestrians are solved, and on the number of red-walkers. Problems with red-driving vehicles seem to be of less interest.

Tables 1 and 2 also show that the count of pedestrian accidents is small, and a very large number of intersections would be required to allow reliable interpretation. For this reason an alternative to count of accidents was sought.

Table 1. Number of pedestrian accidents, 22 signalized intersections in Stockholm

	Vehicle			
	turning		straight through	
	with green	against red	with green	against red
Pedestrian walking with green	39	0	0	14
against red	0	0	54	0

Table 2. Number of pedestrian accidents, 12 signalized intersections in Malmoe

		Vehicle			
		turning		straight through	
		with green	against red	with green	against red
Pedestrian walking	with green	19	0	0	5
	against red	0	0	17	0

4. TRAFFIC CONFLICTS TECHNIQUE

In this study pedestrian safety has been estimated using a TCT. Efforts to find good accident surrogates were started by Perkins and Harris (1967). Since then, different TCTs have been developed around the world [in, e.g., United States, France, Britain, Germany, Holland and Sweden; see International Committee on Traffic Conflicts Techniques (ICTCT) 1982].

The definition of a conflict varies between the different techniques. However, all nations participating at the first workshop on traffic conflicts (TØI, LTH 1977) agreed on the following general definition:

> A traffic conflict is an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged.

In the Swedish technique developed at the Department of Traffic Planning and Engineering in Lund (Hydén 1977) the following specific definition is used:

> A serious conflict occurs when two road-users are involved in a situation where a collision would have occurred within 1.5 seconds, if both road-users had continued with unchanged speeds and directions. The time is calculated from the moment one of the road-users starts braking or swerving to avoid the collision.

The reason that conflict studies were used in this study instead of accident analyses is partly because pedestrian accidents are rare (and only part of them are recorded) and partly because conflict studies give more information about the causes.

Conflicts are recorded by observers at the site. Tests show that observers, after approximately five days of training, are able to recognize serious conflicts with a high degree of reliability. About 80% of the situations are correctly judged, when compared with an objective evaluation from video tape, as to whether they are serious conflicts or not. This means that the conflict frequency for a chosen period can be established with high accuracy. Typically, conflicts are counted at a site for a relatively short time period (1–10 days). Thus, the conflict frequency represents only this time period and not necessarily a longer period because of day-to-day variability in conflict frequency. A typical day-to-day variation for the Swedish technique seems to be approximately equal to the daily average (Hydén 1987).

The validity of the technique for pedestrian accidents has been examined by juxtaposing conflict counts and accident histories from 115 intersections (Gårder 1985). The average accident to conflict ratio was found to be 12.5×10^{-5} accidents/conflict and the site-to-site variance of this ratio is estimated at 32.4×10^{-10} (accidents/conflict)^2. These two numbers allow us to establish the accuracy with which the expected number of accidents can be estimated. It can be shown, for example, that a one-day conflict count gives more accurate estimates of the expected number of accidents than a one-year accident history, if the expected number of accidents is less than 5 per year, or a three-year accident history if the expected number of accidents is less than 1.7 per year (assuming that the number of accidents follows the Poisson distribution).

5. RELATION BETWEEN ACCIDENT RISK AND INTERSECTION DESIGN

Using the TCT, risk to pedestrians has been studied at 115 intersections in Stockholm and Malmoe. The aim was to estimate the expected number of pedestrian accidents per unit of exposure for signalized and unsignalized intersections. Therefore, traffic volume counts were undertaken parallel to the conflict studies so that the relevant exposure could be calculated.

The study refers only to intersections in built-up areas. All the intersections studied are traditional four-way intersections with crosswalks on all arms. Separate signal displays for pedestrians exist at all crosswalks. The number of lanes on each arm varies between two and six. Traffic volumes vary widely (between 5,000 and 25,000 ADT). An example of a typical layout is given in Fig. 1.

The intersections have been separated into signalized and nonsignalized. The latter group was split according to the average driving speed through the intersection. Because of the relatively small data base only two speed categories were defined. The three types of intersections were thereby defined as follows:

(i) Signalized intersection = Intersection with conventional two-phase signal.
(ii) Low-speed intersection = Nonsignalized intersection with mean speed on all arms below 30 km/h.
(iii) High-speed intersection = Nonsignalized intersection with mean speed above 30 km/h on at least one arm.

The intersections have then been classified according to geometrical design. The following variables were considered:

(i) street width (i.e. the length of the crosswalk) (l),
(ii) the distance between the crosswalk and the "curb" (d),
(iii) existence of refuge (r).

The variables are defined as shown in Fig. 2.

For each arm, accident frequency and exposure have been calculated for different time periods of the day. A total of 1,728 observations were thereby obtained. Accident

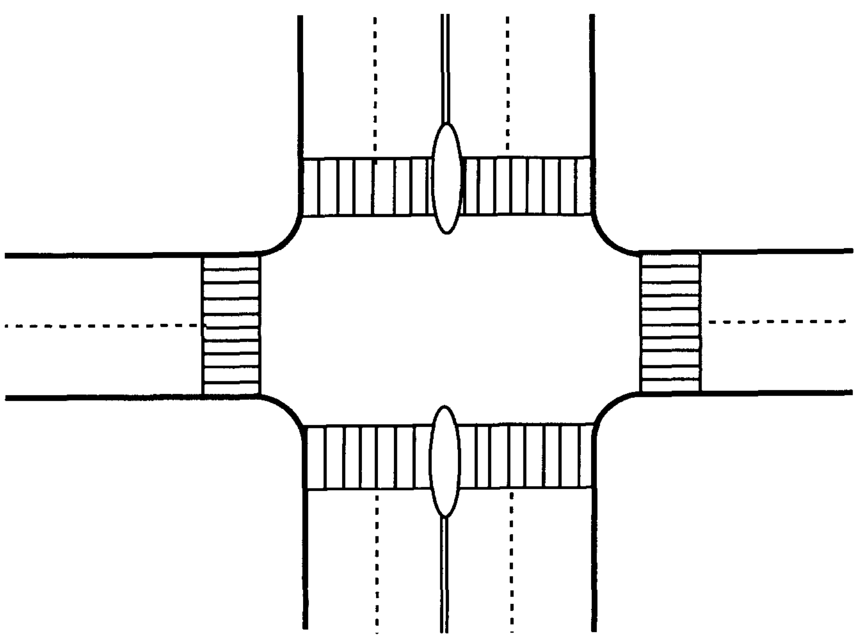

Fig. 1. A typical layout for studied intersections.

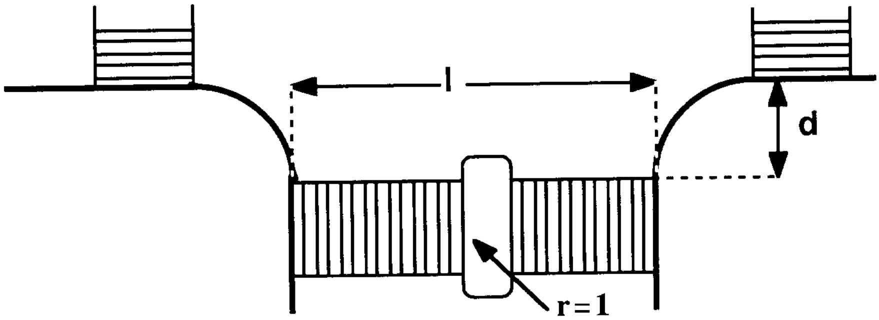

Fig. 2. Definition of variables.

frequency was estimated from conflict counts. Based on a literature review by Nilsson (1978) the following definition of exposure was chosen: "Exposure = the square-root of the product of the number of pedestrians per hour and the number of motor-vehicles per hour that may get involved in a conflict with the pedestrians." (At this stage it was assumed that all road users obey traffic signals.)

It has been assumed that for a specific layout there is a correlation between accident frequency and exposure. This was tested by linear regression through the origin and t-test. In the cases where this correlation has been established, a risk has been estimated as the ratio between the estimated accident frequency and the exposure (i.e. the slope of the regression line). The selection of intersections was not primarily made for this project, but was made randomly according to the layout. Some risk estimates have, therefore, not been possible to determine. The other risk estimates are presented in Table 3.

When comparing risk estimates of signalized and nonsignalized intersections it should be noted that exposure (as defined here) is reduced when a signal is installed. The amount of reduction depends on the proportion of turning vehicles. This means that the effect of signalization on safety is greater at intersections with a high proportion of turning vehicles than at intersections where most vehicles go straight through. An example of the safety effect of signalization is given below:

Consider an intersection that is presently not signalized and belongs to the "*high-speed*" group. One of its arms has the following characteristics:

$$l = 12 \text{ m}, d = 4 \text{ m}, r = 1,$$

$$\text{pedestrian flow} = 100 \text{ ped/h, vehicle flow} = 1{,}000 \text{ veh/h.}$$

As is one should expect: $0.264\ (100 \times 1{,}000)^{1/2}10^{-2} = 0.83$ acc/year.

Assume now that the intersection is *signalized.*

(i) Assuming *a high percentage of turning vehicles*, say a vehicle flow of 600 veh/h while pedestrians are supposed to cross, one should expect:

$$0.286\ (100 \times 600)^{1/2}10^{-2} = 0.70 \text{ acc/year (16\% reduction of risk).}$$

(ii) Assuming *a low percentage of turning vehicles*, say a vehicle flow of 100 veh/h while pedestrians are supposed to cross, one should expect:

$$0.286\ (100 \times 100)^{1/2}10^{-2} = 0.29 \text{ acc/year (65\% reduction of risk).}$$

If the intersection belonged to the "*low-speed*" group before signalization the expected accident frequency would originally have been $0.132\ (100 \times 1{,}000)^{1/2}\ 10^{-2} = 0.42$ acc/year. *Signalization* would then give an increase of risk with about 67% in the example with the high percentage of turning vehicles, while the risk would be reduced with approximately 31% in the examples with the low percentage of turning vehicles.

Table 3. Results from linear regression: risk estimates and their significance

Intersection type	Distance from cross-walk to "curb"(m)	Existence of refuge	Street width (m)	Number of sites (intersec-tion arms)	Estimate of risk acc/100 years (exposure=1)	Correlation coefficient	Significance level (t-test)
	0.0-1.9	No	<10.0	20	0.153	0.262	not significant
			10.0-15.0	4	0.000	-	not significant
L			>15.0	0	-	-	not significant
O		Yes	<10.0	0	-	-	not significant
W			10.0-15.0	0	-	-	not significant
			>15.0	4	0.052	0.007	not significant
S	2.0-10.0	No	<10.0	36	0.051	0.140	not significant
P			10.0-15.0	100	0.164	0.339	0.1%
E			>15.0	4	0.369	0.165	not significant
E		Yes	<10.0	48	0.119	0.452	1 %
D			10.0-15.0	180	0.132	0.318	0.1 %
			>15.0	16	0.105	0.247	not significant
	10.1-30.0	No	<10.0	0	-	-	not significant
			10.0-15.0	4	0.115	0.164	not significant
			>15.0	0	-	-	not significant
		Yes	<10.0	8	0.017	0.034	not significant
			10.0-15.0	8	0.083	0.201	not significant
			>15.0	0	-	-	not significant
	0.0-1.9	No	<10.0	8	0.000	-	not significant
H			10.0-15.0	8	0.000	-	not significant
I			>15.0	0	-	-	not significant
G		Yes	<10.0	8	0.061	0.238	not significant
H			10.0-15.0	28	0.144	0.171	not significant
			>15.0	12	0.000	-	not significant
S	2.0-10.0	No	<10.0	72	0.451	0.221	5 %
P			10.0-15.0	48	0.000	-	not significant
E			>15.0	12	1.626	0.451	10 %
E		Yes	<10.0	84	0.166	0.423	0.1 %
D			10.0-15.0	244	0.264	0.221	0.1 %
			>15.0	140	0.467	0.292	0.1 %
	10.1-30.0	No	<10.0	4	1.415	0.055	not significant
			10.0-15.0	0	-	-	not significant
			>15.0	0	-	-	not significant
		Yes	<10.0	8	0.106	0.455	not significant
			10.0-15.0	8	0.000	-	not significant
			>15.0	4	0.000	-	not significant
	0.0-1.9	No	<10.0	0	-	-	not significant
			10.0-15.0	8	0.124	0.776	not significant
S			>15.0	0	-	-	not significant
I		Yes	<10.0	8	0.000	-	not significant
G			10.0-15.0	40	0.140	0.278	5 %
N			>15.0	60	0.124	0.391	0.1 %
A	2.0-10.0	No	<10.0	4	0.180	0.254	not significant
L			10.0-15.0	36	0.286	0.384	1%
I			>15.0	8	0.030	0.019	not significant
Z		Yes	<10.0	28	0.027	0.127	not significant
E			10.0-15.0	116	0.286	0.300	0.1 %
D			>15.0	272	0.198	0.245	0.1 %
	10.1-30.0	No	<10.0	0	-	-	not significant
			10.0-15.0	0	-	-	not significant
			>15.0	0	-	-	not significant
		Yes	<10.0	16	0.046	0.192	not significant
			10.0-15.0	12	0.111	0.310	not significant
			>15.0	0	-	-	not significant

The influence of one factor probably varies with the value of other factors, as well as with variables not included in this study. It is, therefore, impossible to give reliable values to the influence of single factors. Below is, however, an attempt to give approximate guidance.

(i) Low-speed intersections are about half as dangerous as high-speed intersections.

(ii) Signalization of a high-speed intersection reduces accident risk to approximately half.

Table 4. The influence on pedestrian risk from introducing scramble

Site	Number of serious conflicts with pedestrians			
	without scramble	with scramble	reduction	significance of reduction
Stockholm I	27	17	10	1%
Stockholm II	18	15	3	-
Esloev	27	3	24	0.1%

(iii) Signalization of a low-speed intersection reduces accident risk as long as a large percentage of the vehicles are not turning.

(iv) Decreasing road width to less than 10 m can reduce accident risk by up to 60%.

(v) Installing a refuge decreases the accident risk to roughly two thirds of the original one.

(vi) The crosswalk ought to be installed less than 2 m away from the intersection.

6. THE SCRAMBLE SYSTEM AT SIGNALIZED INTERSECTIONS

This section examines the consequences of the scramble system of traffic control. Studies were made before and after introduction of scramble at three sites. Two of these sites were in Stockholm and the third in a small town called Esloev (approximately 15,000 inhabitants). In each study, risk was measured as well as motor vehicle and pedestrian delay. The expected accident rate was estimated with the use of the Traffic Conflicts Technique. There was hardly any change in traffic volumes between the before and after studies. The conflict counts show that the number of serious conflicts (and thereby accident risk) has not changed for vehicle drivers or cyclists. The number of serious conflicts involving pedestrians was reduced, as shown in Table 4.

The scramble manoeuvre appears to be more effective in Esloev than in Stockholm. This can be explained by differences in the number of red-walking conflicts. These were, in the after-study, 16 and 10, respectively, for the two intersections in Stockholm. In Esloev there was not a single one. This is probably associated with large differences in the percentage of red-walkers. In Esloev the percentage was less than 1%. In Stockholm it varied between 10% and 50% for different crosswalks.

Pedestrian delays and passing times of vehicles increased considerably, as can be seen in Table 5.

The conclusion of this study is that the scramble manoeuvre can be an efficient safety measure as long as the percentage of pedestrians crossing on red is low. Whether it is a measure that is economically possible to defend is, however, uncertain. In Esloev, for example, the total effect of scramble (using time and accident costs from the Swedish National Road Administration) gives a daily loss of about US $100 in 1986 prices. This is derived from summing up different consequences, as shown in Table 6.

7. THE INFLUENCE OF VARIOUS FACTORS ON THE PERCENTAGE OF PEDESTRIANS CROSSING ON RED

Two different methods were used in this investigation. "Intersection-related" factors were studied through behavioral studies, and "human" factors were studied through

Table 5. Influence on delays from introducing scramble

Site	Increase in mean passing time for vehicles		Increase in mean delay for pedestrians	
	No. of sec.	%	No. of sec.	%
Stockholm I	+ 5.3	+ 22	+ 4.1	+ 93
Stockholm II	+ 7.7	+ 39	+ 0.3	+ 4
Esloev	+ 16.2	+ 73	+ 6.0	+ 74

Table 6. An example of a consequence analysis of introducing scramble in a small town

Daily extra delay for vehicles: 22 hours x US $ 6	= - US $ 132
Daily extra delay for pedestrians: 3 hours x US $ 4	= - US $ 12
Profit through decreased number of personal injury accidents per day: 0.0006 x US $ 65 000	= +US $ 39
Environmental and other consequences	= -
SUM (daily)	= - US $ 105

interviews. Below, the two parts are described separately. All the intersections studied had separate signal displays for pedestrians.

Intersection-related factors

To test the influence of various intersection-related factors, studies of red-walking frequency were carried out at 152 crosswalks at 38 intersections in 15 different towns. Each crosswalk was studied during five periods, spread throughout the day. Traffic counts were undertaken simultaneously with the frequency studies. Thereafter, data was collected on the design of the intersection. A multiple regression analysis was then made on the data. Out of this a model has been developed. This model can be used to predict the percentage of red-walkers on a crosswalk at a signalized intersection. It can also be used to analyze the influence of the different factors. There may be other intersection-related factors that have not been considered in the model. Furthermore, the influence of human factors has not been considered. In spite of this the model gives a high degree of explanation. The multiple correlation coefficient got the value 0.83. The model looks as follows:

$$Y = 9.8\,T - 0.79\,W + 5.4\,R - 9.3\,P + 8.2\,F_G - 4.8\,F_R + 0.017\,X + 4.0\,S + 8.8\,A - 3.9,$$

where

Y = the percentage of red-walking pedestrians out of the number of pedestrians that arrrive on red;
T = town size: $T = 1$ if population is less than 30,000; $T = 2$ if population is between 30,000 and 200,000; $T = 3$ if Malmoe (240,000 inhabitants); $T = 4$ if Gothenburg (440,000 inhabitants); $T = 5$ if Stockholm (660,000 inhabitants);
W = street width in meters;
R = 1 if refuge exists, else 0;
P = number of pedestrians per hour on the crosswalk/1,000;
F_G = number of cars that pass the crosswalk during a green-hour of the pedestrian signal/1,000 (mostly turning cars);
F_R = number of cars that pass the crosswalk during a red-hour of the pedestrian signal/1,000;
X = red-time in seconds at the pedestrian signal during a cycle;
S = 1 if time-fixed signal, 2 if vehicle-actuated;
A = 1 if push-button use is needed for pedestrians to get green, else 0.

The following factors were also tested: weather, centrality of the intersection, and if the intersection had scramble or not. None of these factors turned out to have any significant influence on the number of red-walkers.

From the model it can be seen that traffic volumes and town size have the greatest influence. In other words, besides vehicle flows it is not the detailed design that primarily determines the number of red-walkers, but in what town size the intersection is situated. The larger the city the greater the number of red-walkers. The geometrical design influences the level of red-walking as well. Narrow streets have more red-walkers than wide streets and the presence of a refuge increases the red-walking with approximately 5 units of percent (e.g. from 10 to 15). However, other reasons might make it hazardous to take the refuge away. The number of turning cars when the pedestrian signal shows green also influences the proportion of red-walking. If the number of turning cars is large, introducing scramble may, therefore, decrease the red-walking. The waiting time for green turned out to have very little influence.

Human factors

The interview study was carried out in Stockholm, Malmoe, and Lund (approximately 50,000 inhabitants). In total 450 persons were interviewed. It was found that the person who most often walks against red is a young man. He walks against red three times as often as the average pedestrian. Generally, men walk against red about 40% more than women. The fact that a person is in a hurry naturally influences his behavior. On average, a person who says he is in a hurry walks about 60% more against red than a person who says he is not. Hurry influences men's behavior to walk against red more than women's. How often the pedestrian passes the intersection does not seem to influence the red-walking, nor is there a difference in the behavior between pedestrians who have a driver's license and those who have not.

Furthermore, the studies show that there are two "types" of pedestrians, those that almost never walk against red light, and those that frequently do so. Countermeasures against red-walking should focus on the latter group. More than half the group that more or less always walks against red can spontaneously mention some measure that would decrease their red-walking. The most common proposals are "more supervision by the police" and "better signals." "More knowledge of the accident risk" seems to influence only a very small part of the group. When the group was asked to rank different countermeasures for decreasing red-walking, also here "more supervision by the police" and "shorter waiting time for green" were considered to be the most effective ones.

8. CONCLUSIONS

In Sweden accidents with pedestrians at signalized intersections occur, in the vast majority of cases, because of:

(i) a turning vehicle hitting a green-walking pedestrian, or
(ii) a red-walking pedestrian being hit by a vehicle.

One way of eliminating accidents caused by turning vehicles is to give the pedestrians a separate green phase, e.g. a scramble period. By this a very satisfactory accident reduction is achieved, as long as there is a low percentage of pedestrians crossing on red. However, the delay for both vehicles and pedestrians increases. Whether the total effect is considered positive or not, is a matter of how the different effects are valued. At places were red-walking is common—in the bigger cities—scramble can hardly be recommended. It might even increase the risk for pedestrians because of further increase in the red-walking frequency.

Decreasing the number of accidents with red-walkers would best be done by decreasing the number of red-walkers. The bigger the city the more common red-walking is. It seems difficult to influence red-walking by changes in the geometrical design. The measures that reduce red-walking are often disadvantageous from other safety aspects. For example, increased street width or taking away the refuges reduce red-walking, but give, in spite of this, a total negative effect on pedestrian safety. The most efficient way to reduce red-walking seems to be a change in attitude. This can probably best be done by making the signals "as good as possible" for pedestrians (e.g. short waiting times) and police enforcement against red-walking. It can, however, be argued that police enforcement of minor violations, such as red-walking, is not desirable.

Finally, it should be pointed out that there are often cheaper countermeasures than signals that give a comparable effect on pedestrian safety. Such measures are, however, not studied here.

REFERENCES

Bång, K. L. Signalreglering och trafiksäkerhet, en före- efterstudie. Stockholms gatukontor, rapport nr. 14. Stockholm; 1969.

Cameron, M. H.; Stanton, H. G.; Milne P. W. Pedestrian accidents and exposure in Australia. Proceedings from International Conference on Pedestrian Safety. Haifa, Israel: Technion; 1976.

Gårder, P. Theory for strong validation, application to Swedish results. Proceeding from Evaluation 85. International Meeting on the Evaluation of Local Traffic Safety Measures. Paris. Arceuil, France: Organisation National de Securité Routière; 1985.

Hydén, C. A. Traffic-conflicts technique for determining risk. Bulletin 15 B. Lund, Sweden: Department of Traffic Planning and Engineering, Lund Institute of Technology; 1977.

Hydén, C. The development of a method for traffic safety evaluation—the Swedish traffic conflicts technique. Bulletin 70. Lund, Sweden: Department of Traffic Planning and Engineering, Lund Institute of Technology; 1987.

International Committee on Traffic Conflicts Techniques (ICTCT). In: Kraay, J. H., editor. Proceedings of the Third International Workshop on Traffic Conflicts Techniques (organized by the ICTCT). Leidschendam, The Netherlands: Institute for Road Safety Research, SWOV; 1982.

Jörgensen, N. O.; Rabani, Z. Fodgaengers sikkerhed i og ved fodgaengerovergange. Rådet for trafiksikkerhedsforskning. Rapport 7. Copenhagen; 1971.

Kraay, J.; Slop, M.; Oppe S. Safety of pedestrian crossing facilities. Utrecht, The Netherlands: Utrecht Traffic Department; 1974.

Nilsson, G. Riskmassor. Strukturering av behov av riskmassor för trafikanalys. VTI rapport nr 144. Linköping. Sweden: VTI; 1978.

Older, J.; Grayson, G. An international comparison of pedestrian risk in four cities. Proceedings from International Conference on Pedestrian Safety. Haifa, Israel: Technion; 1976.

Perkins, S. R.; Harris, J. L. Traffic conflict characteristics; accident potential at intersections. Warren, MI: General Motors Corporation; 1967.

Short, M.; Woelfl, G.; Chang, C.-I. Effects of traffic signal installation on accidents. Accid. Anal. Prev. 14:135–145; 1982.

TØI, LTH. In: Amundsen, F.; Hydén, C., editors. Proceedings: First Workshop on Traffic Conflicts. Oslo, Norway: Institute of Transport Economics; 1977.

Trafiksäkerhetsverket, Sverige. Trafiksäkerhetsprogram 1987. Borlänge, Sweden; 1987.