THE EFFECT OF SIGNALIZATION ON ROAD ACCIDENTS IN HELSINKI

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ABSTRACT

This paper investigates the effect of signalization on road accidents in Helsinki, Finland. The results indicate that the signalization particularly increased the safety of the minor road of T-intersections. However, the study also implies that traffic signals are not necessarily suitable for all types of intersections. For example, the safety effect of public transport signalization varied in different environments. The deactivation of traffic signals during night time was found to increase the road accidents.

Accident rates were higher in general in signalized intersections compared to unsignalized intersections. The accident rate decreased along with the increase of the traffic volume, but the accident rate of signalized intersections increased again when the daily traffic count exceeded 50 000 vehicles. The accident rate also increased when the amount of phases of the signal operation increased. This implies that red light offences increase when the intersection capacity decreases.

Rear-end collision is the most common accident type in signalized intersections. A comparison to previous studies shows that the proportion of rear-end collisions at signalized intersections has not decreased since 1985. This result indicates that vehicle-actuated traffic control has not solved the problem of rear-end collisions.

1. INTRODUCTION

1.1. International studies

Over the years, safety effects of signalization have been investigated many times all over the world. In various studies signalization has been found either to increase or decrease the safety or to have no significant effect. This indicates that safety does not only depend on the signalization itself, but also on other elements, including the operation of the signals.

The earliest reported study on this subject carried out in the U.S.A. in 1933 considered 599 intersections and found that installation of traffic signals to result in a 20 % overall decrease in accidents. On the other hand, in a later study carried out in California in 1970 new signal installation at 179 intersections was found to result in a 27 % reduction in the total number of accidents. However, accidents were found to increase by 24 % after installation of traffic signals in 1975 in Virginia, while accidents were found to decrease by 7 % in 1982 in New York. [1]

Golias discusses the inconsistency in the results described above concerning changes in junction safety due to installation of traffic signals. The inconsistency is not surprising given that the safety effect of signal installation depend on a complex set of factors e.g. the geometric design of the intersection, the traffic characteristics, the accident history, etc. [1]

Al-Mudhaffar et al. have suggested improvements to the Swedish actuated signal control technique to resolve the stop-or-go dilemma for divers caught in the so-called "dilemma zone" upon signals change to amber. The improvements included moving the detectors closer to the stop line and making the detectors speed dependent. The results showed a significant safety effect when the function was in operation, shown by a reduction in red-light violation. [2]

1.2. Signalization in the city of Helsinki

The population of the city of Helsinki is 600,000 and the average vehicle ownership density is approximately 400 cars/1000 inhabitants. In the end of year 2009 there was a total number of 460 signalized intersections and approximately 5200 unsignalized intersections in the capital of Finland. The installation of traffic signals is based on flows of conflicting traffic streams, prioritization for public transport or traffic safety e.g. accident records or a need for pedestrian signals near schools. All traffic signals in Helsinki are in general vehicle actuated signals and the green times changes dynamically according to traffic flows. Traffic signals on main routes are usually interlinked and coordinated to optimize green waves for the main traffic flows. Helsinki also has special partial signalization for bus priority. These special traffic signals are called Jokeri signals and are operating only when a bus or tram is approaching the intersection to give prioritization for public transport. A scheme for the operation of Jokeri signals is provided in Figure 1.

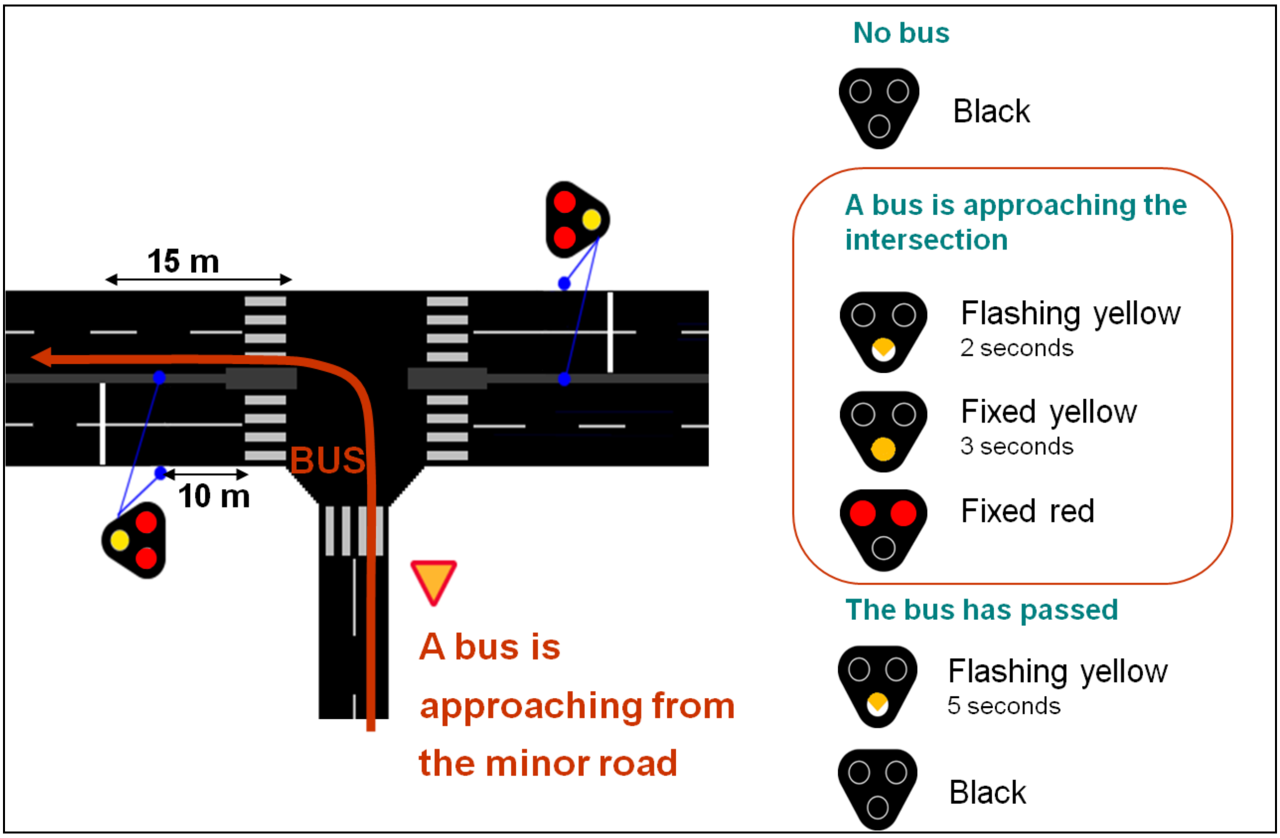

Figure 1 - Operation scheme for Jokeri signals used for public transport prioritization in city of Helsinki.

1.3. Earlier studies in city of Helsinki

City of Helsinki, the capital of Finland, has an average of 2600 road accidents a year. Crashes in signalized intersections account for approximately 33 % of total accidents.

Safety effects of signalization have been investigated in Helsinki since 1970. A study by Koivu discusses the changes in recorded accidents after the implementation of traffic signals. According to the study, the total number of all accidents decreased with 14-27 % after the implementation of traffic signals depending of the signal operation. However, the total number of injury accidents was unchanged. For injury accidents it seemed that the reduction of crossing accidents was replaced by the increase of rear-end accidents. In the same study, traffic signals are claimed to be most suitable for traffic flows between 10 000 and 25 000 ADT when regarding traffic safety. [3]

A study conducted by the City Planning Department of Helsinki in 1985 indicates that a remarkable number of accidents occur in signalized intersections while the signals are not operating. Of these accidents nearly 60 % occur while the signals are inactive on purpose e.g. during night time. Furthermore, the results showed that traffic signals improve traffic safety in four-legged intersections, but signalization is not necessary always a good solution for three-legged intersections. [4]

1.4. Objective of the study

The objective of this study was to analyze the traffic safety at signalized intersections in the city of Helsinki as well as to determine whether installation of signalization or different operations of signals affect traffic safety.

2. METHODOLOGY AND DATA COLLECTION

2.1. Data collection

Accident data were collected for all signalized and unsignalized intersections in the city of Helsinki, Finland. Years 2000-2008 were chosen for the data collection, since accident counts in the long-term are not necessary comparable due to changes in traffic regulations, speed limits, attitudes, the financial situation, vehicle stock etc.

Of all recorded accidents during years 2000-2008 only accidents considered relevant for this study were included in the study. These accidents were within 50 m distance from the intersection or of an accident type possibly affected by the traffic control of the intersections. Irrelevant accident types excluded from the study were for example overtaking accidents, loss of control accidents, single accidents and pedestrian accidents outside pedestrian crossings.

Therefore, all accident counts presented in this paper include only accidents considered as relevant for this study. The relevant accident data consisted of a total number of 11,428 accidents.

In addition to the accident records geographical data of the intersections and the accidents, data of traffic flows as well as data of signal operation was used in this study.

2.2. Methodology

The effect of signalization on traffic safety was determined by using simple statistics as well as before-after studies. The effect of signalization on road accidents was described by the change in the total number of accidents, by accident type distributions, the proportion of injury accidents, accident rates etc. Accident rate describes road accidents per 1.000.000 cars entering an intersection. The estimation of the difference of two proportions was determined for 90 %, 95 % and 99 % confidence [5].

The before-after study was conducted to determine the change in accident counts and types after implementation of traffic signals. Sites where traffic lights were implemented during years 2003-2006 were chosen to the study to get at least 3 year long "before" and "after" periods. The lengths of the "before" and "after" periods varied from site to site. The intersections studied included 12 signalized intersections and 7 Jokeri signals.

Unsignalized comparison sites were chosen for the signalized intersections to help establish the mean trend of accident counts without improvements in both the "before" and "after" period. The chosen intersections experience very similar traffic flows as the treatment sites. The empirical Bayes (EB) method was used to estimate the number of accidents in the "after" period without the treatment. [6] Because of the small sample size and lack of statistical significance, a graphical analysis was conducted to analyze whether the signalization has an effect on the location of the accident in the intersection.

A loglinear model was used to estimate the safety effect of converting incandescent bulbs to light emitting diodes (LEDs). The estimation was done by using comparison sites and explanatory variables. Explanatory variables used in the model were traffic flow, data of the "before" or "after" periods, and the data of the signal type.

3. RESULTS

3.1. Effect of signalization on accident counts and accident types

3.1.1 Accident counts and rates

According to accident records, 6294 traffic accidents occurred at signalized intersections and 5134 accidents at unsignalized intersections in Helsinki during years 2000-2008. The proportion of injury accidents was 22 % in signalized intersections, which is smaller compared to the proportion, 29 %, at unsignalized intersections. The number of fatal accidents varied between 1-4 accidents/year in both intersection types.

Helsinki has a total number of 460 signalized intersections and approximately 5200 unsignalized intersections. During years 2000-2008 at least one accident occurred in 90 % of the signalized intersections while 70 % of the unsignalized intersections were without accidents. However, these numbers are not directly comparable, since the number of unsignalized intersections includes intersections on minor streets with low traffic volumes.

Accident rates were higher in general in signalized intersections compared to unsignalized intersections. Figure 2 displays accident rates for different traffic volumes in signalized and non signalized intersections. At both signalized and unsignalized intersections the accident rate decreased as the traffic volume decreased, but at signalized intersections it started to increase when the average daily traffic (ADT) exceeded 50 000 vehicles.

Compared to unsignalized intersections, signalized intersections are usually complex and the number of potential conflicts is high. High traffic volumes in signalized intersections require many lanes and might lead to complex signal arrangements, and the simplicity of the traffic operation is lost. Red light offences might also increase along with the decrease of capacity and level of service. Unsignalized intersections with high traffic volumes are usually ramp intersections in interchanges, where the proportion of traffic volume on the ramp is small compared to the main road.

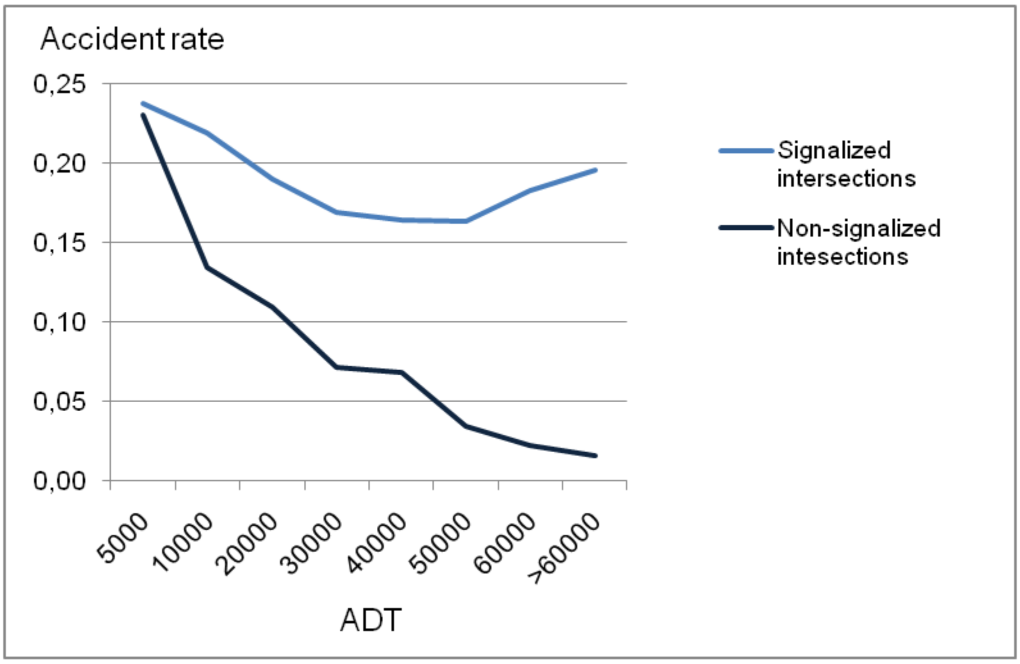

Figure 2 - Accident rates for different traffic volumes in signalized and unsignalized intersections.

A comparison of accident rates in Figure 2 to accident rates in roundabouts implied that accident rates in roundabouts do not differ significantly from accident rates in signalized and unsignalized intersections. [7]

3.1.2 Accident types

The large proportion of rear-end collisions is a well known safety problem at signalized intersections which has been demonstrated in several previous studies, for example in the study carried out by Koivu in 1974 and the study carried out by City Planning Department of Helsinki in 1985. [3, 4] According to the latter study rear-end collisions accounted for 33 percent of the total accidents at signalized intersections and for 31 percent of the total injury accidents. Other common accident types in signalized intersections were crossing accident (18 % of the total accidents) and turnover accident (18 % of the total accidents). The accident-type distributions for signalized and unsignalized intersections are shown in Figure 3. The distributions are very similar except for the proportions of rear-end collisions and crossing accidents.

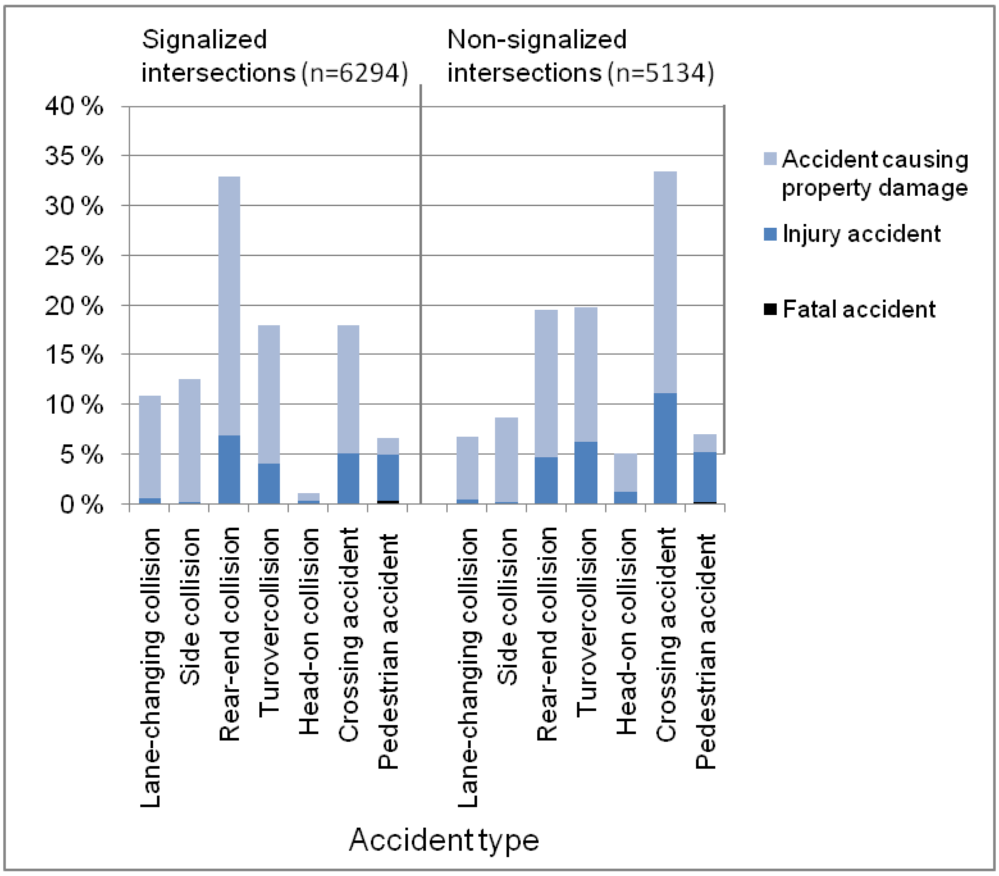

Figure 3 - Accident types in signalized and unsignalized intersections.

3.1.3 Before-after analysis

Three- and four-legged intersections

The results from the before-after analysis indicate that the average number of accidents decreased slightly at T-intersection. Due to the small sample size and other changes done at the intersections during the data collection period, it was not possible to determine the safety effect of four-leg intersections.

In contrast to the number of accidents, the variation of accident types after the installation of signalization was statistically significant. Rear-end collisions increased (level of significance 5 %) and turning accidents decreased (level of significance 10 %) in the "after" period. The increase of rear-end collisions and decrease of turning and crossing accidents after installation of traffic signals have been presented in several previous studies, for example in the study carried out by Koivu in 1974 and the study carried out by City Planning Department of City of Helsinki in 1985. [3, 4]). The implementation of traffic signals had least effect on pedestrian accidents. Even with this small sample size, the accident type distribution before and after the implementation of signalization is very similar to the accident type distribution for signalized and unsignalized intersections (Figure 3).

Graphical analysis of the accidents indicates that after implementation of traffic signals the safety in T-intersections especially improved for the minor road. In three cases out of nine there was an accident black spot at the intersection area next to the minor road in the "before" period. In all these cases, the accident black spot disappeared in the "after" period. Figures 4-6 below show the geographical location of accidents in the "before" and "after" periods.

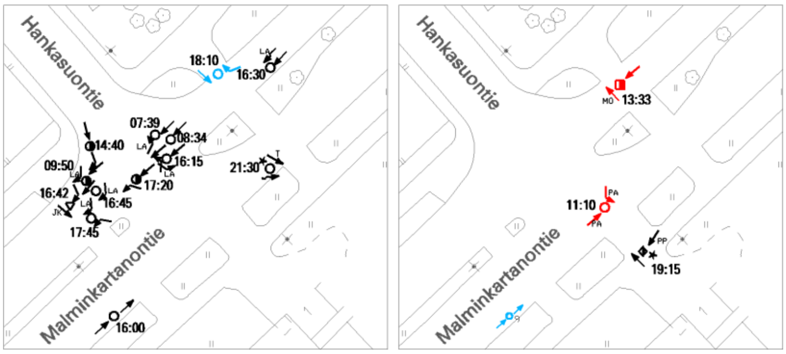

Figure 4 - Accidents before installation of signalization to the left and accidents after installation of signalization to the right.

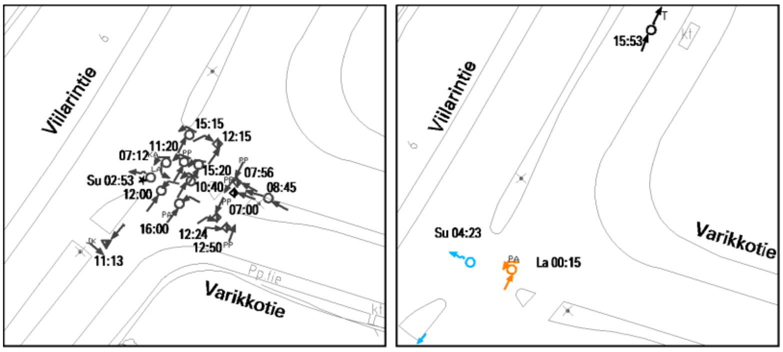

Figure 4 - Accidents before installation of signalization to the left and accidents after installation of signalization to the right.

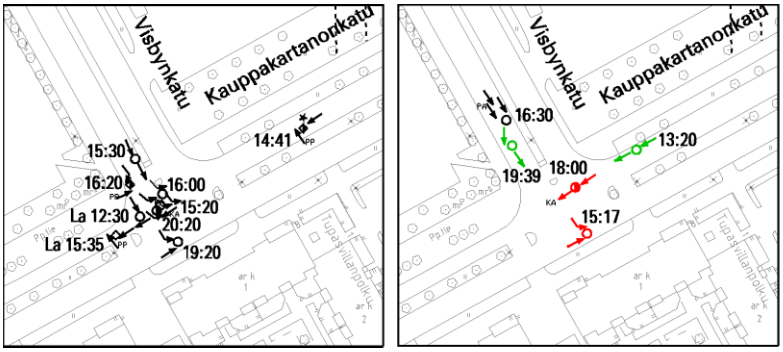

Figure 4 - Accidents before installation of signalization to the left and accidents after installation of signalization to the right.

Special signalization for bus priority

Of the 7 intersections studied, 4 sites were without accident records in both the "before" and the "after" periods. In the 3 intersections with recorded accidents the safety effect of the signalization varied in different environments. Figure 5 shows accidents in an intersection with special signalization for bus priority. The Jokeri signals were installed immediately after the building of the bus street ("Maaherrantie") and therefore the "before" period is missing. Even if the "before" period is missing, the crossing accidents indicate a lack of safety in the intersection.

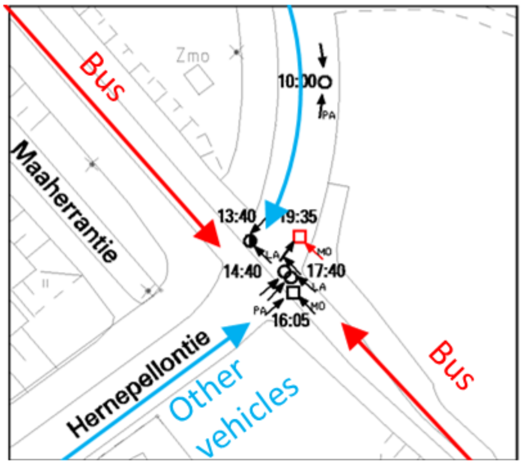

Figure 5 - Accidents in an intersection with public transport prioritization.

It was not possible to determine the safety effect of Jokeri signals, but this study indicated safety problems at some intersections, and hence the effect of signalized bus priorities on road accidents needs further studies.

3.2. Effect of signal operation on traffic safety

3.2.1 Signal deactivation

Approximately half of the signals in city of Helsinki are not operating during night time. The average accident rate (1.17) during night time in the intersections with non-operating signals was approximately four times larger compared to the average accident rate (0.3) during night time in the intersections where the signals are operating in the night.

Accident rates for sites where the signals were not operating during night time were highest in the area of Helsinki's rectangular street layout. A comparison of accident rates during night time for selected intersections in the area of Helsinki's rectangular street layout is provided in Table 1. The selected intersections represent signalized intersections that are operating and not operating during night time, as well as unsignalized intersections as comparison sites. The selected intersections experience very similar traffic flows and intersection geometry.

Table 1 - Average accident rates during night time in selected intersection at the rectangular street network.

	Average accident rate	Intersections	Accidents	Alcohol related accidents
Singalized intersections, where the traffic signals always are operating	4,20	18	52	(7)
Comaparitison sites:				
Signalized intersections, where the traffic signals are not operating during night time	0,38	6	2	(0)
Non-signalized intersections	0,54	10	3	(1)

The numbers in the table above indicate, that the average accident rate is notably larger at signalized intersections deactivated during night time than at compared to the comparison sites. Of the 18 selected sites with non-operating signals during night time, only 4 sites were without accident records. Accidents related to alcohol consumption did not account for the large number of the accidents. The small accident rate at non-signalized intersections implies that it is not the lack of signalization but rather the deactivation of traffic signals that increases the accident rate during night time.

The deactivation of traffic signals has also a significant effect on accident types Rear-end collisions are the most common accidents at signalized intersections in general. However, crossing accidents account for more than 50 % of the accidents when the traffic signals are not operating. The proportion of crossing accidents while the signals are deactivated is even larger than the proportion of crossing accidents at unsignalized intersections (significance lavel 1 %). Furthermore, the proportion of rear-end collisions decreases to approximately 10 % when the signalization is not operating. The proportion of crossing accidents is especially large in the CBD (rectangular street network) where the sight distances are short. The deactivation of traffic signals did not significantly affect pedestrian accidents.

The analysis indicates that the deactivation of traffic signals increases the proportion of injury accidents. The proportion of injury accidents was 25 % when traffic signals were activated and 32 % when they were not operating. The last-mentioned proportion is close to the average share of injury accidents in unsignalized intersections, which was 29 %.

These results indicate that traffic signals should be operating around the clock.

3.2.2 Number of phases

The accident rate at signalized intersections increased when the number of phases of the signal operation increased. The average accident rates for different numbers of phases are provided in Table 2. The increase of the accident rate suggests that red light offences increase when the intersection capacity decreases. This also implies that the simplicity of the traffic control and traffic regulation is lost for complex signal operation in multiple phases.

Table 2 - Accident rates according to the number of phases for the signal operation.

Number of phases	Accident rate	Number of intersections
2	0,10	190
3	0,19	150
>4	0,22	96

3.3. Effect of new signalization technology on traffic safety

3.2.3 Rear-end collisions in vehicle actuated traffic signals

Rear-end collisions are a known problem for signalized intersections, especially for signalization with fixed cycle lengths. Vehicle-actuated traffic signals optimize green times dynamically according to traffic flows and the position of the vehicles. The detectors and extensions of green times aim to minimize red light offences and rear-end collisions.

Still at the beginning of 1980's all traffic signals in city of Helsinki were operating with fixed cycle lengths, most of them with fixed timing. In the current decade, all traffic controllers in

Helsinki are vehicle-actuated and equipped with detectors. Accident data from 2000-08 were compared with accident data from signalized intersections gathered in Helsinki in 1985 [4] to determine whether vehicle-actuated traffic signals have decreased the proportion of rear-end collisions. Unexpectedly, the share of rear-end collisions have increased (significance level 1 %) since 1985. Summary data for this comparison is provided in Table 3. However, these numbers are not directly comparable due to changes in speed limits, attitudes, financial situation, vehicle stock etc.

Table 3 - The share and number of rear-end accidents for accident records from 1979-82 and 2000-08.

Time for accident records	**The share (and number) of rear-end accidents**
1979-82	28,0 % (n = 530)
2000-08	33,0 % (n = 2074)

3.2.4 LED-signals

The safety effect of converting incandescent bulbs to light emitting diodes (LEDs) was studied in 11 intersections. Comparison sites were used for each intersection. According to accident records, accidents increased by 21 % in the treatment sites while the accidents decreased by 7 % in the comparison sites. On the contrary, the safety effects of the conversion to LEDs were estimated by a loglinear model, and the results showed no statistical significance in the increase of accident records. However, a study by Eustace et al. indicates that accidents increased by 71 % after converting to LED signals. [8]

On the other hand, LED signals reduced the share of rear-end collisions (statistical significance 10 %). Visibility of LEDs is superior, which could positively affect driver behavior and visual range.

4. CONCLUSIONS

The results of this study demonstrated that signalization does not improve safety at all types of intersections, but the operation of the signals may have a significant safety effect. For example, the safety effect of signalization for public transport prioritization varied in different environments. However, the results indicate that the signalization increased especially the safety of the minor road of a T-intersection. Accident black spots at T-intersections next to the minor road disappeared after installation of traffic signals.

The share of injury accident was smaller at signalized intersections compared to unsignalized intersections. However, the proportion of injury accidents at signalized intersections was smaller only when the signals were activated. The deactivation of traffic signals during night time increased the share of injury accidents and the accident rates increased remarkably particularly in the rectangular street network of the CBD. Unsignalized intersections in similar areas were not as dangerous during night time, implying that it is not the lack of signalization but rather the deactivation of traffic signals that increases the accident rate.

Accident rates were higher in general in signalized intersections compared to unsignalized intersections. At both signalized and unsignalized intersections the accident rate decreased along with the increase of the traffic volume, but at signalized intersections it started to increase when the average daily traffic (ADT) exceeded 50 000 vehicles. High traffic volumes at signalized intersections require many lanes and might lead to complex signal arrangements, and the simplicity of the traffic operation is lost. The accident rate also increased when the number of phases of the signal operation increased. This suggests that red light offences may become more frequent as capacity decreases.

Rear-end collision were the most common accident type at signalized intersections and accounted for approximately one third of the total number of all accidents as well as of the injury accidents. Furthermore, crossing accident is the most common accident type in unsignalized intersections. However, crossing accidents account for more than 50 % of the accidents when the traffic signals are not operating. The share of crossing accidents was especially large in the area of Helsinki's rectangular street layout where the sight distances are short.

A comparison to a study carried out in Helsinki in 1985 demonstrated that the share of rear-end collisions in signalized intersections has not decreased since 1985. This implies that vehicle-actuated traffic control has not solved the problem with rear-end collisions. On the other hand, LED-signals seems to reduce the share of rear-end collisions.

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