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— DRIVE Project V1031

An Intelligent Traffic System for Vulnerable Road Users

TRIALS WITH MICROWAVE DETECTION OF VULNERABLE ROAD USERS AND PRELIMINARY EMPIRICAL MODEL TEST

L. Ekman and M. Drasköczy (eds.)

Deliverable No. 11
Workpackage 9: Preliminary Empirical Model Test
Workpackage Leader: L. Ekman, Lund Institute of Technology

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PUBLIC REPORTS OF DRIVE PROJECT V1031

Workpackage 1

Ekman, L. and Drasköczy, M. (1989) Problems for vulnerable road users in Sweden. Final report for workpackage 1 of DRIVE project V1031: An intelligent traffic system for vulnerable road users. WP 299, Institute for Transport Studies, University of Leeds.

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Tight, M.R., Carsten, O.M.J. and Sherborne, D.J. (1989) Problems for vulnerable road users in Great Britain. Final report for workpackage 1 of DRIVE project V1031: An intelligent traffic system for vulnerable road users. WP 292, Institute for Transport Studies, University of Leeds.

Workpackage 2

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Workpackage 3

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Workpackage 4

Sherborne, D.J., Schagen, I.N.L.G. van and Ekman, L. (1991) Microwave detection of vulnerable road users: three feasibility trials carried out at traffic signal locations. Final report for workpackage 4 of DRIVE project V1031: An intelligent traffic system for vulnerable road users. WP 335, Institute for Transport Studies, University of Leeds.

Workpackage 5

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Workpackage 6

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TABLE OF CONTENTS

1 INTRODUCTION

L. Ekman and M. Drasköczy

The general objective of the project is to provide a set of tools for the creation of traffic systems that enhance the safety and mobility of vulnerable road users (VRUs). This is being achieved in two ways:

1. By evaluating a number of RTI applications in signalling and junction control, in order to ascertain what benefits can be obtained for vulnerable road users by such local measures.

2. By developing a model of the traffic system that incorporates vulnerable road users as an integral part.

The present workpackage, one of the last ones within the project, is intended to link the two strands together.

The workpackage consists of two main parts:

1. Experiments with pedestrians and bicyclists. Two experiments were carried out, one in England (Bradford) and one in Sweden (Växjö), both applying microwave detectors for detection of pedestrians in a signalized intersection, but applying the detection in different ways. An observational study was carried out in Groningen (the Netherlands) to analyze bicycle/car interactions at an intersection with a cycle path. The aim of the experiment was to test the usefulness of a system giving car drivers warning in situations when a bicyclist approaches an intersection on a parallel bicycle path.

2. Reliability and validity testing of the submodels of the VRU-oriented traffic model VULCAN.

2 EXPERIMENTS WITH MICROWAVE DETECTION OF PEDESTRIANS AND BICYCLISTS

2.1 THE COMMON EXPERIMENTAL VARIABLES

L. Ekman and M. Draskóczy

The present work has been in many respects a continuation of the trial experiments carried out in Workpackage 4 (Sherborne, Van Schagen and Ekman, 1991). The link has been closest in the Bradford experiment which was run at the same location and was a modified version of the same experimental setting. In the case of Växjö and Groningen the link was not so close, but the results of the trial experiments were applied in the design.

Although the characteristics of the locations and the details of the experiments are different, there was a need to define in advance some common variables for observations and evaluation.

The definitions of the main variables were as follows:

1. Traffic conflicts — the term is used according to the Swedish Traffic Conflict Technique (Hydén, 1987). In this technique, a conflict is defined as a traffic event, involving at least two road users, that would have resulted in an accident if none of the involved road users had taken any evasive action (braking, accelerating or swerving). The seriousness of a conflict is determined on the basis of time to accident (TA) and estimated speeds of the road users involved. The TA is defined as the time from the moment one of the involved road users starts an evasive action until the collision would have occurred if no evasive action had been undertaken. Figure 1 gives the TA/speed trade-off scheme for serious and non-serious conflicts.

2. Red light violation

   a/ pedestrians: pedestrians arriving on the red phase of the signal and not waiting until green. Three subgroups can be distinguished:
   - late walkers: starting walking in the first two seconds of the pedestrian red phase,
   - early walkers: starting walking in the last two seconds of the pedestrian red phase,
   - others.

   b/ bicyclists: bicyclists arriving on the red phase of the signal and not waiting until green. Three subgroups can be distinguished:
   - late riders: starting riding in the first two seconds of the cyclist red phase,
   - early riders: starting riding in the last two seconds of the cyclist red phase,
   - others.

   c/ cars: cars arriving on the red phase of the signal and not waiting until it turns green.

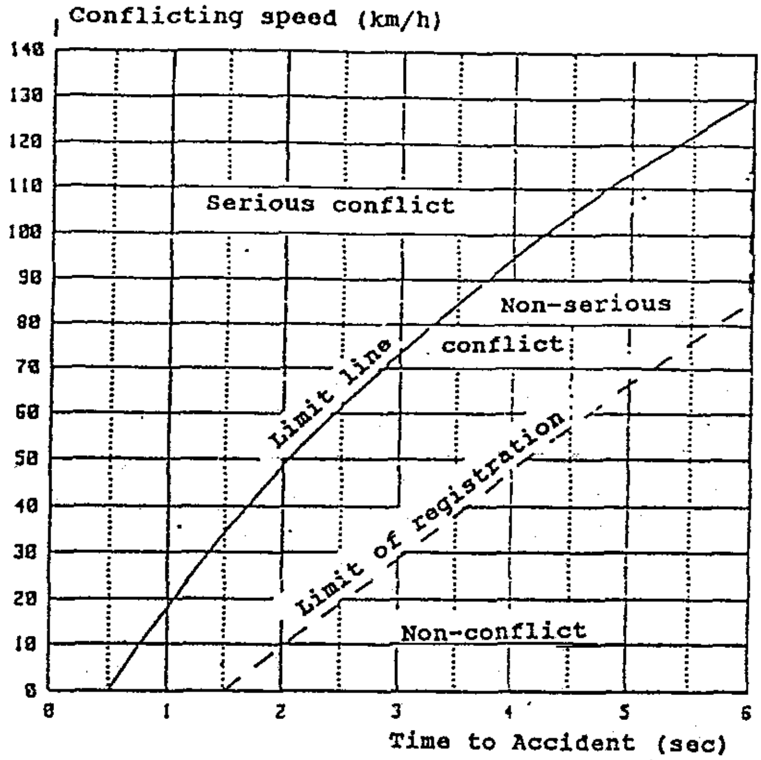


Figure 1: Determination of Conflict Severity

3. Delay time
a/ pedestrians: the time from the moment the pedestrian stops at the kerb until the moment he/she steps to the road in order to cross it. Four subgroups can be distinguished:
   - red arrivals when at least one disturbing car is present
   - red arrivals when no disturbing car is present
   - green arrivals when at least one disturbing car is present
   - green arrivals when no disturbing car is present.

b/ bicyclists: the time from the moment the bicyclist arrives at 20 meters distance from the traffic light until the moment he/she reaches a point 3 meters before the traffic light, minus the average travel time of that distance for undisturbed bicyclists.

c/ cars: the time from the moment the vehicle comes to a complete stand still until the moment the vehicle starts moving when the light turns green and the vehicle in front is moving as well.

Red light violators should be omitted from the sample of all the three groups.

4. Unnecessary green for pedestrians — the number of automatic activations of the pedestrian green when no pedestrian crosses during the green phase.

5. Reliability of detection — the proportion of actually detected road users among the total number of road users of a given class arriving in the detected area.

2.2 THE BRADFORD TRIALS

D.J. Sherborne

2.2.1 Introduction

In the first stage of the trials reported in Deliverable 9 (Sherborne, Van Schagen and Ekman, 1991), microwave pedestrian detectors were installed at two locations in Bradford. The results from these trials were reported in more detail in Deliverable 9, but in brief the results showed that the detection devices could be used at both signal locations to improve the response of the signals for pedestrians. However, the results of the trial at the pelican crossing did not show any measurable change in the safety performance of the crossing. This was due to the fact that the existing safety performance of the crossing was very good and so there was very little improvement possible. But the trial carried out at the signalized crossroads showed that the effect upon the safety for both pedestrians and drivers was improved by using the response from the detectors to increase the all-red time during the signal phase changes. It was therefore decided to increase the scope of the trial in the second phase of the project by repeating the work carried out at the signalized junction, but this time to increase the all red time to 5 seconds whenever a pedestrian was detected approaching the crossing. The aim of this work was firstly to further verify that the detectors would work for an extended period, but secondly to examine the effects, both of safety and movement, on all the road users at the location. The results from this further stage are fully presented in this deliverable, together with an overview analysis of the conclusions arising from all stages of the trial.

2.2.2 Method

The basic methodology was exactly the same as that described in Deliverable 9 (Sherborne, Van Schagen and Ekman, 1991), and the location of the junction is shown in Figure 2. (For a detailed description of the site see Section 3.6.1 in Deliverable 9). Microwave detectors were installed in the same positions as the previous experiment to detect pedestrians approaching the junction (see Figure 3).

The controlling mechanism of the signal installation was then adjusted once again by GEC so that, upon receipt of the signal from the detection equipment, the all-red time would be increased from 1 to 5 seconds at the next change in the signal phasing. (Following the completion of the first trial, the detection equipment was disconnected and the all-red time on the signals reverted to a fixed 1 second). The signals were left in this state for 3 weeks to allow the situation to settle down. Following this period the observations were carried out to determine exactly what was happening for all road users at the junction and these results were then analyzed.

As previously stated, the objective of the study was to obtain confirmation of the effectiveness of the trial by evaluating:

a) Reliability of Equipment
b) Safety for pedestrians
c) Safety for drivers
d) Changes in pedestrian behaviour.

The overall goal of the DRIVE project is to make the highway safer for the vulnerable road user without undue detriment, if possible, to other road users. In the long term, this

Figure 2: Layout of Trial Junction in Bradford

impovement in safety can be calculated by reductions in either the number of injury accidents or the accident rates (or both). However, in the restricted time allocated for this project, it is not possible to calculate any significant changes in the frequency of accidents, and so the technique of conflict studies was used to evaluate any changes in the safety of the junction. Using this technique it is possible to quantify the potential for accidents involving different classes of road user. Thus pedestrian safety can be assessed separately to vehicular safety, together with changes in the perceived safety of the junction under different conditions.

Figure 3: Microwave Detectors on Existing Traffic Signal

<u>Details of Trials</u>

The timetable for the observations at the signalized junction is shown below:

	Pre Trial		Post 1st Trial		Post 2nd Trial
	Nov 1989	July (1) 1990	July (2) 1990	Sept 1990	May 1991
reliability	–	x	–	x	x
durability	–	x	x	x	x
delay times	x	–	x	x	x
safety effects	x	x	–	x	x

In November 1989, the first observations took place. Delay times, red light violation rates and the number of conflicts were determined. In early July 1990, after the detection equipment had been installed, but before the actual connection with the traffic signal controller had taken place, the safety measurements (red light violations and conflicts) were repeated to determine whether there were any major differences between a winter and a summer period. At the same time the reliability and durability of the equipment was assessed. The detection equipment was then connected to the controller and the changes in signal timings were effected. Two weeks after this, a provisional examination of the effects were carried out to obtain first impressions of the alterations. After a subsequent period of seven weeks, the observations were repeated to assess the effects of the changed signal timings on safety and delay. The working of the equipment was checked regularly during its installation to assess durability and consistency.

Upon completion of this stage, the equipment was disconnected and the all-red phase of the signals was returned to just one second. In April 1991 the same equipment was reconnected with the only alteration being that the all-red time for vehicles was increased to 5 seconds upon pedestrian detection. This system was left in operation until June 1991, with the majority of the readings being taken during May 1991.

2.2.3 Data Collection Procedures

The reliability of the equipment was verified by regular electrical checks. The electrical contacts were checked and the ability of the detectors to respond to pedestrian movement and to trigger off signal alterations was confirmed. In addition on one of the detectors, a small red light was fitted which would light up whenever a detection occurred, thus enabling a manual check to be carried out on the detection device's efficiency. The physical well-being of the equipment was verified by regular visual inspections at which time any physical damage could be observed.

At the end of both trials a full electrical check of the equipment was carried out by a GEC signal engineer who could verify that all the equipment was working efficiently and as per specification.

The effect of the alterations on pedestrian behaviour was evaluated by a combination of manual counts and video recordings. Wherever possible, video recordings were used but in the case of following the routes of pedestrians through the signalized junction some manual counting was carried out. The data were collected both in the peak and off-peak periods and in total over 160 hours of pedestrian and vehicular movements have been analyzed. The particular pieces of information that were collected included:

a) Pedestrian routes
b) Pedestrian delays
c) Pedestrian behaviour relative to the signal timings
d) Vehicular red light violations.

The movements of pedestrians through the junction were coded by means of a schematic diagram (Figure 4). In all cases the sex and age group of the pedestrians were recorded.

For each test period (November, July, September and May), a total of at least fifteen hours of video recording was available for the experimental locations. For each observed crossing, the time between the arrival (standing still) of the pedestrian at the kerb and the start of the crossing manoeuvre was computed.

The effect of the alterations upon the overall safety for all road users at the location was evaluated by carrying out conflict studies at these locations. The conflict observations were carried out on the spot by a Swedish conflict expert who determined the number of

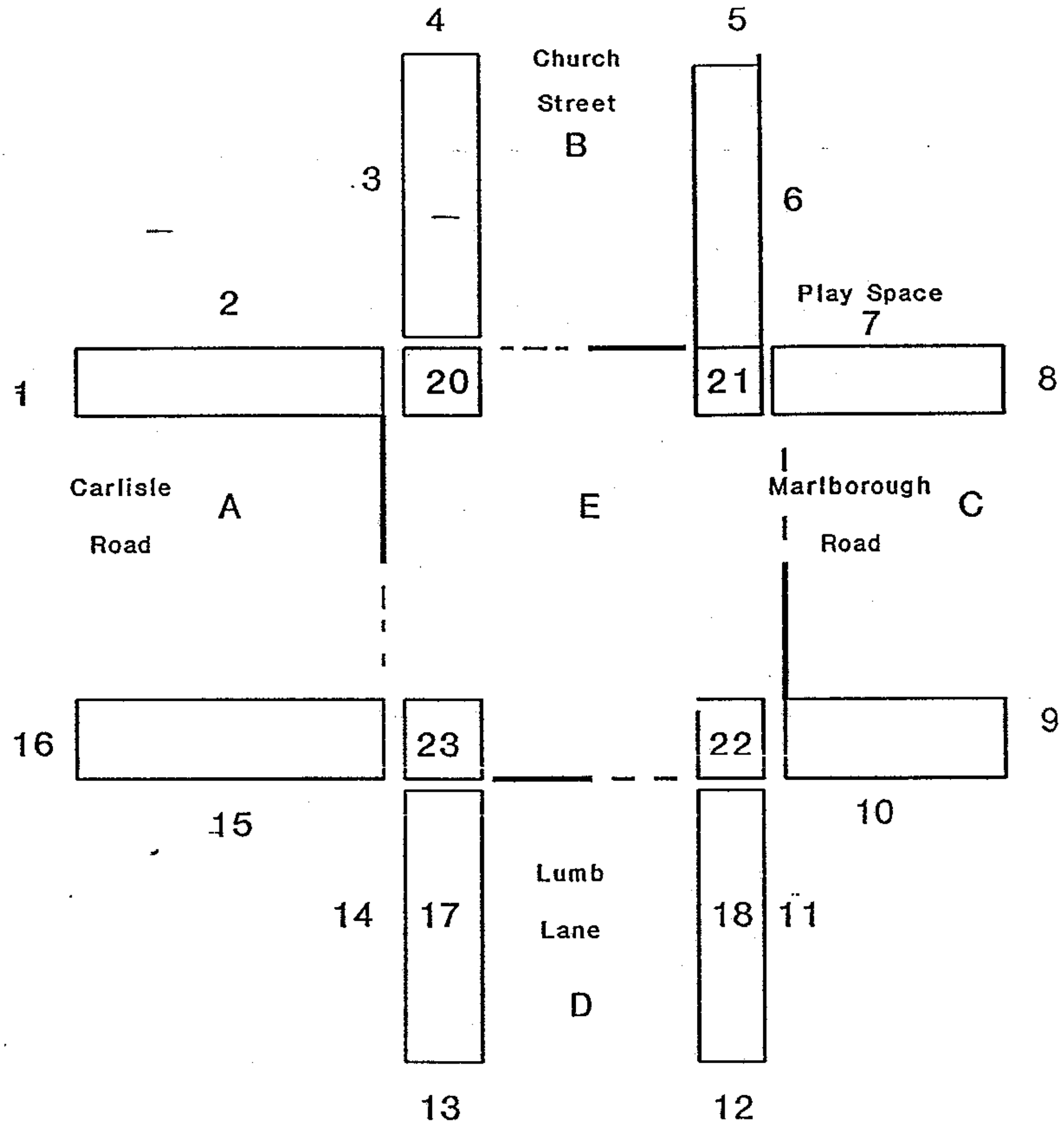


Figure 4: Coding Scheme for Pedestrian Movement at Junction

serious conflicts using the Swedish Traffic Conflicts Technique (Hydén, 1987). The same individual carried out all the conflict studies. For each of the four test periods, the conflict rates were determined on the basis of twelve hours of observation at the signalized junction.

The effects upon the vehicular traffic were not investigated in such a rigorous fashion. The effects of the alterations on the safety at the locations (i.e. conflicts and red-light violations) were however given the same level of importance as for pedestrian safety. The change in capacity of the junction was not evaluated directly, but regular checks were made with the local traffic engineers to ensure that no noticeable deterioration was being observed. In particular, detailed observations were carried out on the effects of the longer (5 seconds) all-red time for vehicles in the final trial as it was anticipated that this might cause some problems.

2.2.4 Results

Throughout all stages of the trial detailed information was stored on data bases relating to the ways in which the locations were seen to be operating. Both objective and subjective factors were used to assess the success of the trials.

Reliability

The results confirmed those given in Deliverable 9 (Section 4.1.1) in that the majority of pedestrians approaching the detectors at the junction were detected. There was still the evidence to show that a significant number of large vehicles (buses and goods vehicles) were detected when they were driven close to the kerb edge. Every detection resulted in the all-red phase being extended to the stipulated amount. These results held for all stages of the trial.

Durability

There were no problems at all with the equipment throughout the length of the trial. No internal, technical or electrical problems were recorded, nor was any of the equipment subjected to vandalism or any other external intervention. At the end of both trials, a comprehensive inspection of the signal controllers and the detector responses was carried out by the regular site maintenance contractors (GEC). They confirmed that the installation was in perfect order. These extensive checks also confirmed that there was no deterioration in the equipment or the connections due to rain, heat or any other adverse external conditions.

Effects for Pedestrians

As previously reported in Deliverable 9, there was no significant change in pedestrian routes or delays between the two pre-trial tests. In the first experimental situation, when there was an all-red time of 3 seconds, there was no detectable change in the number and manner of crossing movements. This conclusion was reinforced by the results of the final trial with the longer all-red time. It was noted that there was no significant increase in the number of pedestrians who took advantage of the longer all-red phase to make diagonal crossings at the junction. This may be a factor of the lack of any external information given at the location: the pedestrians were not provided with any information telling them that the all-red times would be increased, and at the time of the data collection they had perhaps not yet become confident enough to "trust" the system.

Effects for Vehicles

In the first instance the trial was restricted to increasing the all-red time at the change in signal phases to 3 seconds because of the fears by the local Highway Engineers that the additional vehicular delay would increase the congestion at a location which was already susceptible to such occurrences at least for short spells. Following the success of the first trial in not causing such problems, the second stage of the trial was allowed to continue with the all-red time extended to 5 seconds. The results of this were monitored carefully and the capacity of the junction was not adversely affected at all by the reduction in overall green time. The reason for this was that, as indicated by an examination of the videos of the junction, the all-red time was used, at least in part, to allow vehicles to complete right-turn manoeuvres. This cleared the junction and allowed forward-moving traffic to procede more smoothly when the lights changed back to green. There could be some danger in this, in that it might increase the risk to pedestrians using the all-red time to cross the road, but for more details on this see the next section.

Safety Effects

All four sets of conflict studies were carried out at this location and they can be referred to as two "before" sets and two "after" sets. The results are shown in Figures 5–8. As has been explained in Deliverable 9, there is close agreement between the number and type of conflicts in the two before studies; the after study showed a numerical reduction in car-pedestrian conflicts, but this reduction was not significant. The result from the fourth conflict study showed very similar results to that for the first after study.

If the result from the two before studies are combined and then compared within the combined results from the two after studies, then there is a significant reduction in the number of car-pedestrian conflicts. There is no change at all in the number of car-car conflicts.

Red-light Violations

In the light of the fact that the vehicles were going to be waiting for longer periods at the lights ans might be able to see that the vehicles on the other legs of the junction were stationary, there were some fears that the drivers might become impatient and thus go through the lights at red. Examination of the videos showed that there was no increase in the number of red light violations and in fact throughout the whole trial the number of vehicular red-light violations was very small.

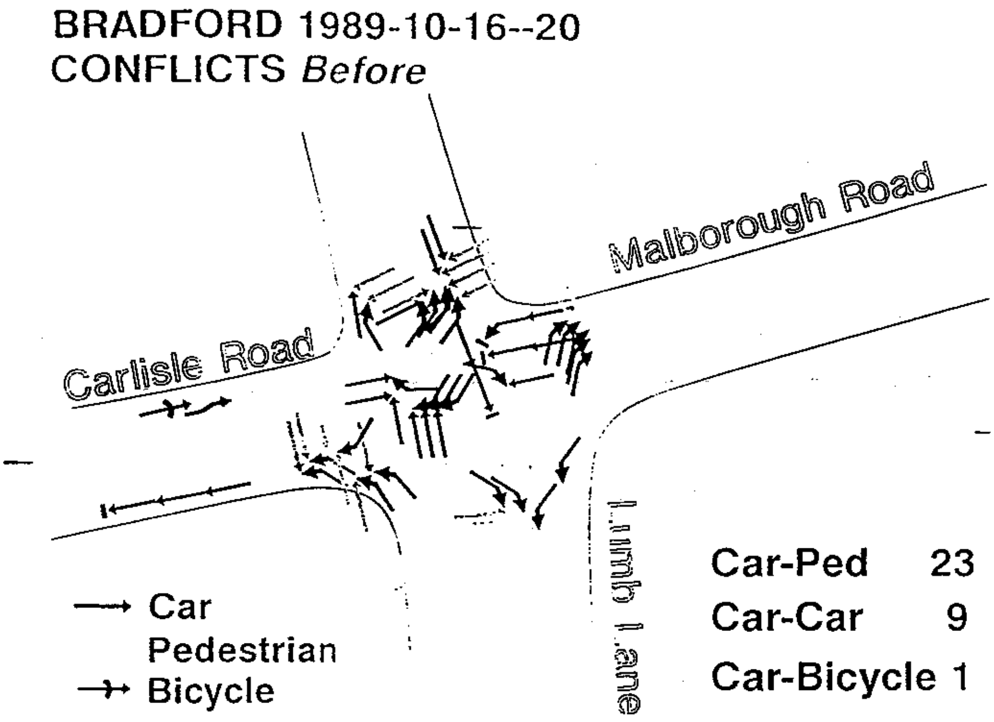


Figure 5: Conflicts at Signalized Junction (First Before Study)

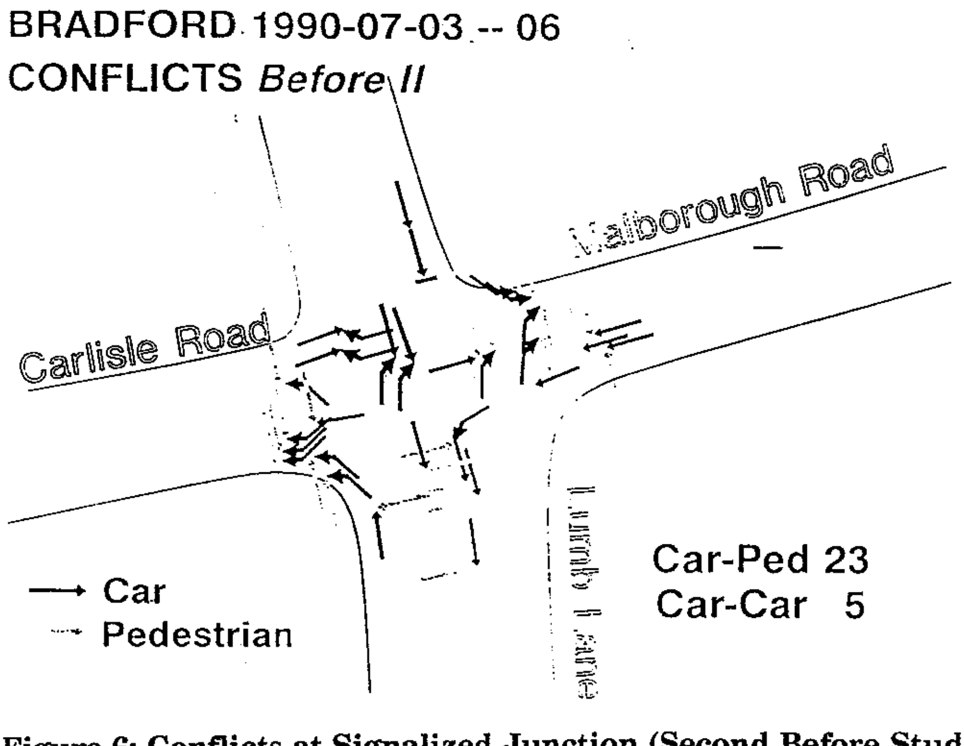


Figure 6: Conflicts at Signalized Junction (Second Before Study)

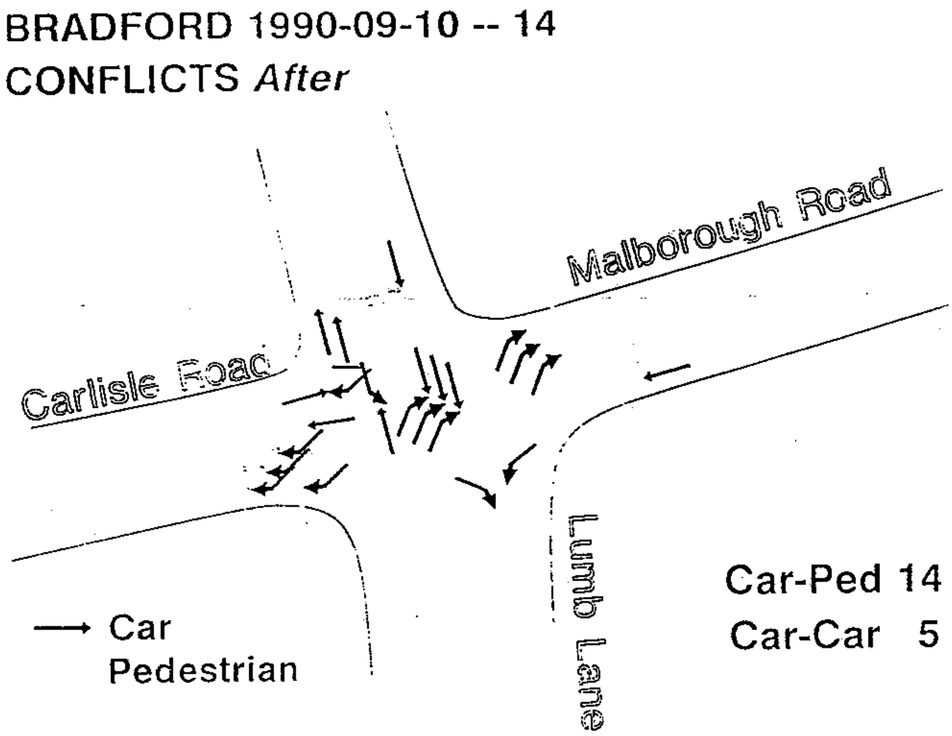


Figure 7: Conflicts at Signalized Junction (First After Study)

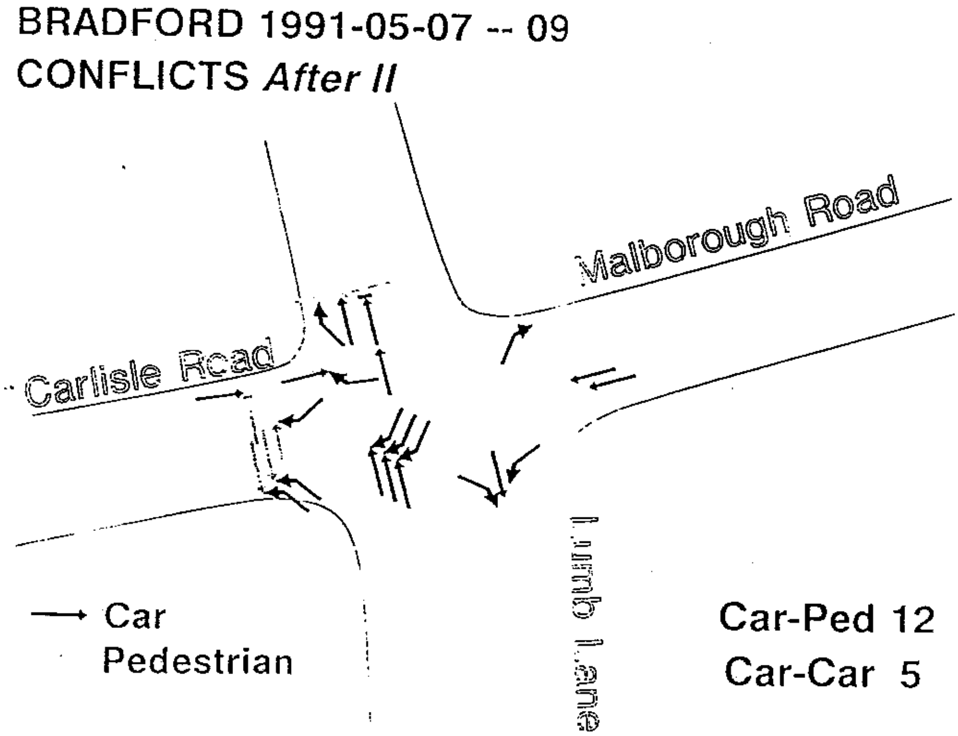


Figure 8: Conflicts at Signalized Junction (Second After Study)

2.2.5 Discussion and Conclusions

The results from this extended trial at the signalized junction confirmed many of the conclusions outlined from Deliverable 9. The detection equipment supplied by H.B. Modules has proved totally reliable and durable in the on-street environment. It has been shown that pedestrians walking on the pavement towards a signalized junction can be detected by microwave equipment and that this response can be used to alter the signal timings.

The safety benefits for pedestrians by increasing the all-red time at the junction have were considerable. There was no change in the safety for vehicles. Rather surprisingly, there was no observable change in the number of pedestrian conflicts when the all-red time was increased from 3 to 5 seconds. The reason for this has not been established, but possibly it shows that the major improvements in pedestrian safety are to be gained from fairly small increases in the time available for pedestrians to cross the roads. However, this conclusion will need to be verified by further work.

All in all, the two pilot trials at the signal location have shown that the use of microwave detectors to amend the signal timings to the advantage of pedestrians is a feasible option and in certain locations can be carried out with minimal disadvantages to vehicular traffic.

2.3 THE VÄXJÖ EXPERIMENT

L. Ekman and M. Draskóczy

2.3.1 Introduction

The experiment was carried out in Växjö (Sweden), at one of the intersections within the network simulated by the pedestrian model. The aim of the experiment was to provide pedestrians with green when their approach to the pedestrian crossing at the signalized intersection was detected, without requiring pedestrians to push the button on the signal pole.

In the pre-experimental situation, the signal phases at the intersection were generally directed by car detectors, and the separate pedestrian signals were all red until a pedestrian pushed the button. Especially in low flow periods, the majority of pedestrians behaved as if the intersection were non-signalized, i.e. they did not push the button but crossed when they felt it to be safe. Another frequent occurrence was that pedestrians pushed the button and then crossed before they got green. Both types of behaviour meant a high percentage of red walking.

Introducing automatic pedestrian detection can give pedestrians green when there is no car approaching and can warn pedestrians that a car is approaching by not giving them green. The expected changes by introducing pedestrian detection were as follows:

- a reduction in red walking,
- a reduction in car-pedestrian conflicts,
- a reduction in the average delay time for pedestrians (especially in the periods of low flow),
- a possible skight increase in delay time for car traffic.

Automatic detection of pedestrians might have negative influences on car traffic because it could result in unnecessary green phases for pedestrians, but this is already a problem with present systems, because many pedestrians push the button but do not wait for the green light. The problem was therefore not likely to be serious, especially in periods of low car flow. When the pedestrian flow was high, the unnecessary detection did not cause any great problems because there was usually a demand from other pedestrians for both pedestrian crossings. Since the cars on the main road (Storgatan) were given a rather high priority, we did not expect a big increase in delay for cars, as pedestrians would only get green when it suited the cars.

2.3.2 Method

Technical Description

Microwave detectors were mounted on four of the eight signal poles at the intersection in order to activate the pedestrian signal when a pedestrian approached. Due to a shortage of detectors, the experiment concentrated on two of the pedestrian crossings — one crossing over the main road (Storgatan) and one over the minor road (Kronobergsgatan). The equipment was essentially identical with that used in Bradford for both WP4 and WP9, but adapted for the 220 volt system used in Sweden. Since most of the pedestrians walked straight ahead and crossed the zebra in a straight line, the detectors were mounted on the signal pole which was normally passed first by the oncoming pedestrian.

Detection of a pedestrian was announced to the signals of both of the pedestrian crossings that might be used by the detected person. The normal push bottom could still be used by the pedestrian if the detection had failed. Figure 9 shows the setup. The dark grey arcs in the figure represents the areas covered by the detectors detecting pedestrians approaching the signal and presumably intending to cross the minor road (Kronobergsgatan). The light grey arcs represents the coverage of pedestrians presumably aiming to cross the major road. The numbers (1 to 14) represent the different events (signal phase, passing vehicle) that were directly recorded by the datalogger in the field.

The design of the evaluation

The effects of the experiment were evaluated by before and after studies. The detectors were installed on site during both periods. This was to eliminate any disturbing effect on road user behaviour caused by the mere presence of the detectors.

The evaluation area which was covered by video cameras was two of the pedestrian crossings (the eastern one at Storgatan and the northern one at Kronobergsgatan) of the intersection. The characteristics that were measured were as follows:

- reliability of the detectors (only in the after-period),
- number of pedestrians crossing and the ratio of red walking,

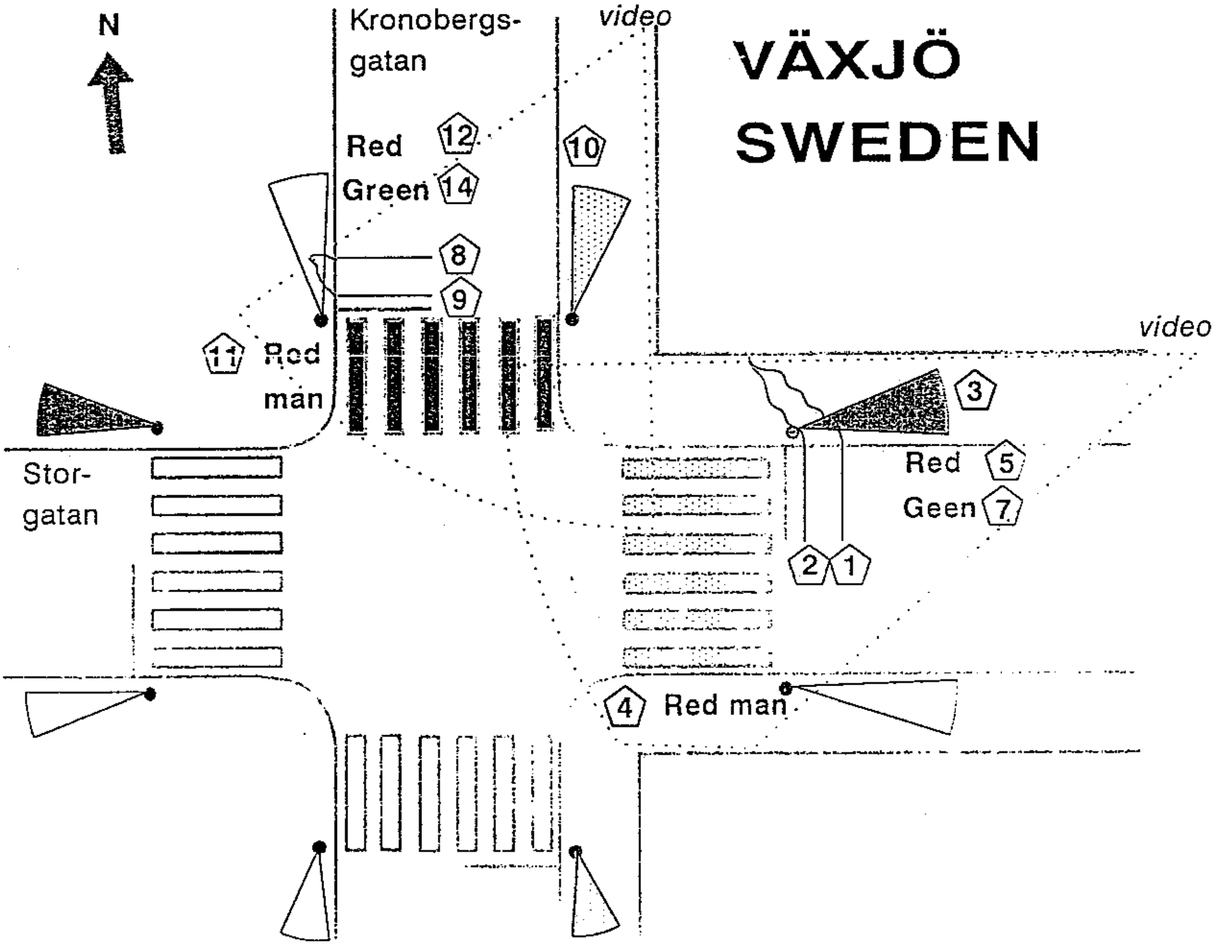


Figure 9: The Experimental Site in Växjö

- delay for pedestrians,
- delay for cars,
- green-time for pedestrians,
- green-time for cars,
- conflicts between cars and pedestrians.

The conflict studies were carried out in the normal way with one observer standing at the spot for one week in a period when there was no other data collection going on, giving a total of thirty hours "before" and thirty hours "after".

A semi-automatic data collection procedure was designed for data collection in the field. Information about events such as changes in signal phase and vehicle detection (by rubber tubes) were recorded directly into the datalogger. The datalogger used was a computer that records events with a precision of one millisecond.

Most of the behavioural data were obtained from the video recordings carried out indoors. The datalogger was connected to the video recorders during recording in such a way that a time code was recorded on one of the audio channels (see Figure 10). The time code was calibrated with the clock in the datalogger every ten seconds, enabling those viewing the video to enter data subsequently to the datalogger which were synchronized with the data collected in the field (see Figure 11). Pedestrian arrival and stepping out on the road were recorded this way.

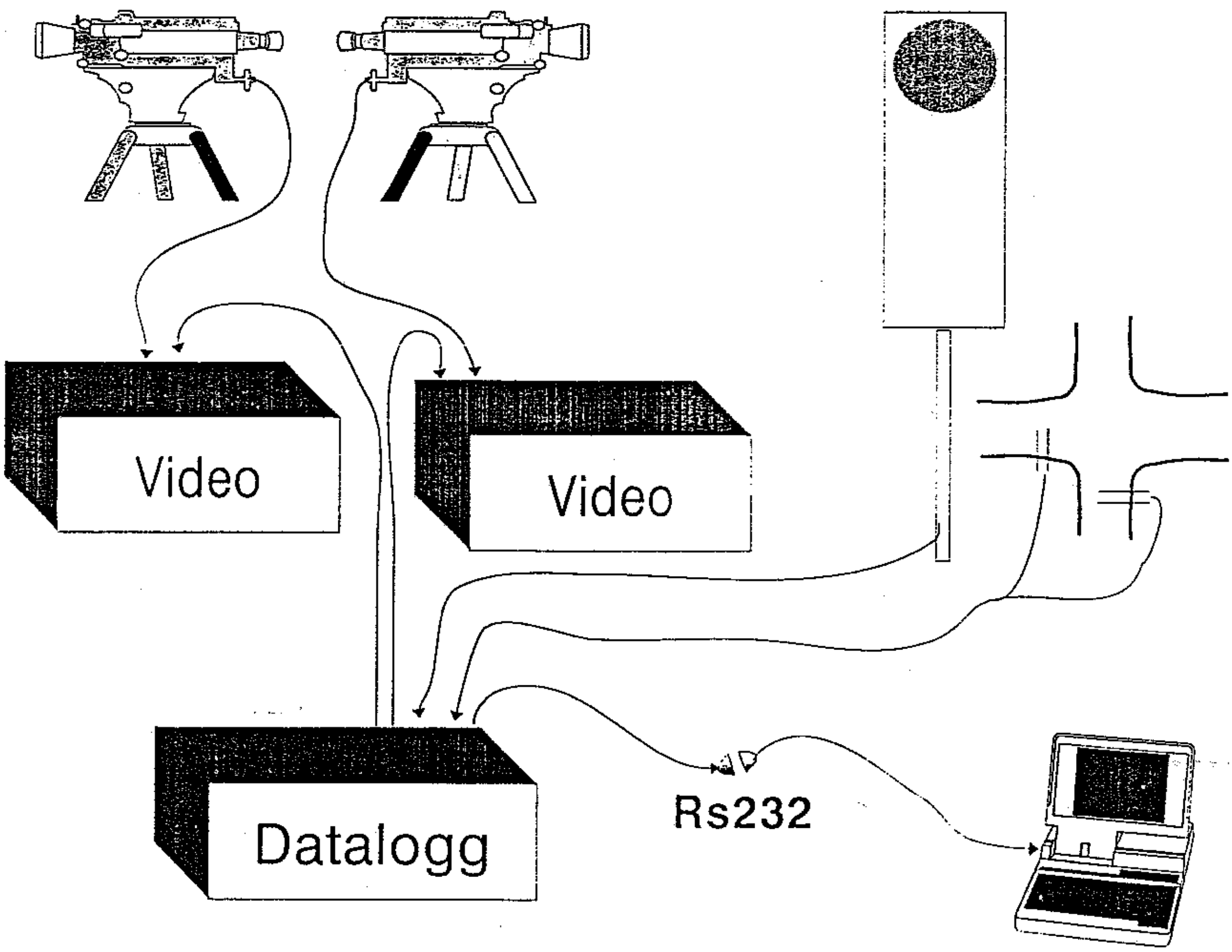


Figure 10: Data Collection Procedure (Outdoor)

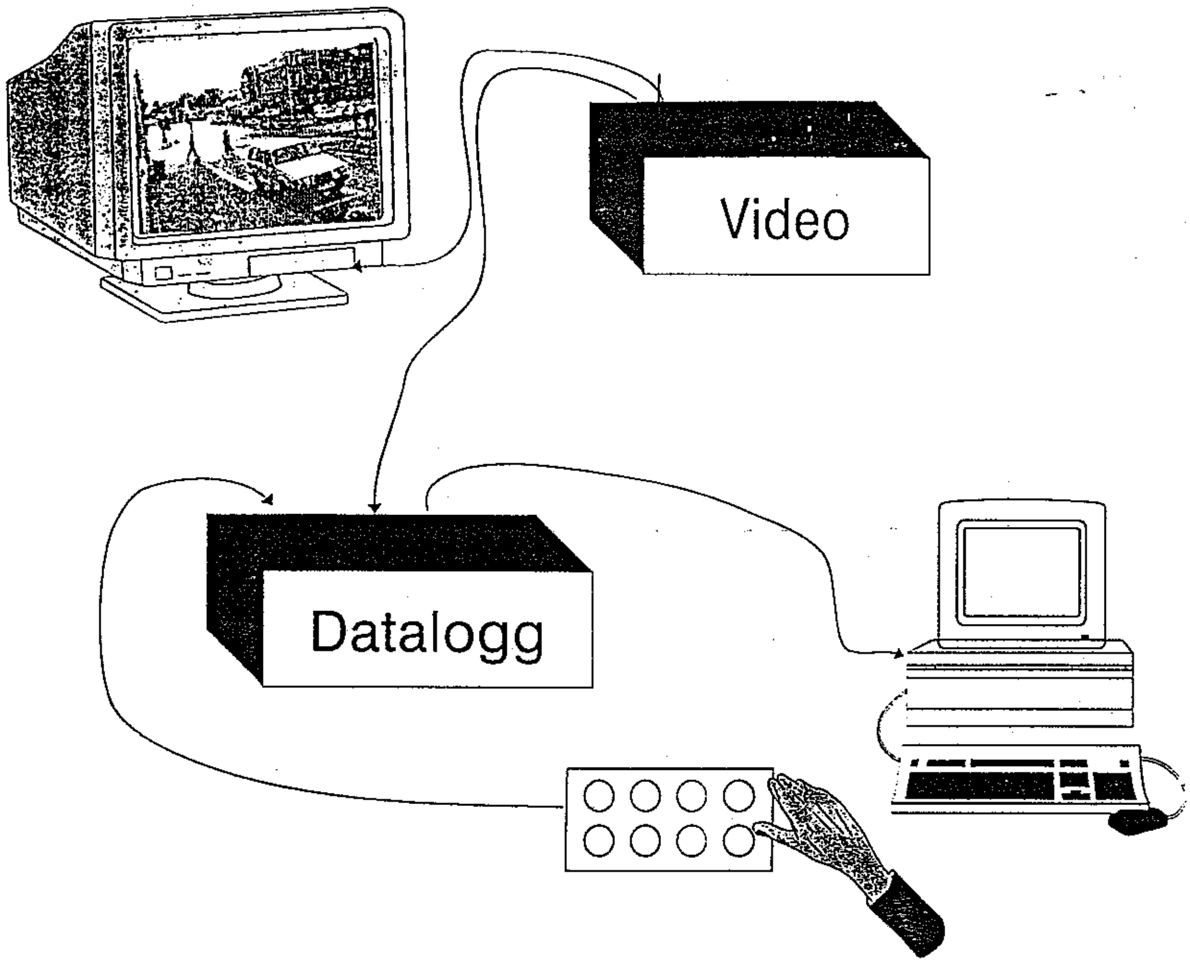


Figure 11: Data Collection Procedure (Indoor)

The analysis of the number of pedestrians walking during red/green light as well as pedestrian and car delay were evaluated by matching these different data sets. A special computer programme was developed for the analysis of data.

2.3.3 Results

Equipment reliability and durability

The reliability of the detectors was good. Pedestrians approaching the intersection were all detected and no problems were found with false detection caused by cars, sun blinds, leaves or other irrelevant things. It was, however, difficult to mount the detectors in a such way that they could detect every pedestrian who wanted to cross and none of those who did not. Pedestrians coming from the zebra crossing and aiming to make another crossing were not detected. Pedestrians just walking around the corner and not aiming to cross the street were almost always detected. False detections did not, however, cause any noticeable problem, firstly because the controller programme favoured vehicles on the major road, and secondly because an unused detection was quite often used by another pedestrian arriving later.

There were some problems with the durability of detectors in Växjö. Three of the detectors failed and had to be repaired during the experiment. Two of the detectors were moved out of position by someone. It is not clear if it this was done for fun or because someone believed that they were being observed by video. It is worth mentioning that many people were convinced that the detectors were video cameras.

Safety effects

The studied intersection was relatively safe even without the detectors, but since this type of intersection is quite common, even minor gains in safety might indicate a large potential for improving safety by detecting pedestrians.

The most important expected safety effect was reduced red walking. Without detection, especially in periods of low traffic, the majority of pedestrians walked against red. Detecting approaching pedestrians reduced red light violation significantly. The reduction was especially large for pedestrians crossing the minor road. This is due to the fact that the controller programme gave high priority to the vehicular traffic on the major road and therefore provided green for pedestrians crossing the minor road. The effect can be seen in Figure 12, where the diagrams located on the pavement show the proportion of pedestrians arriving at red or green, while the diagrams on the zebra crossings show the proportion of pedestrians crossing on red or green by direction for each pedestrian crossing.

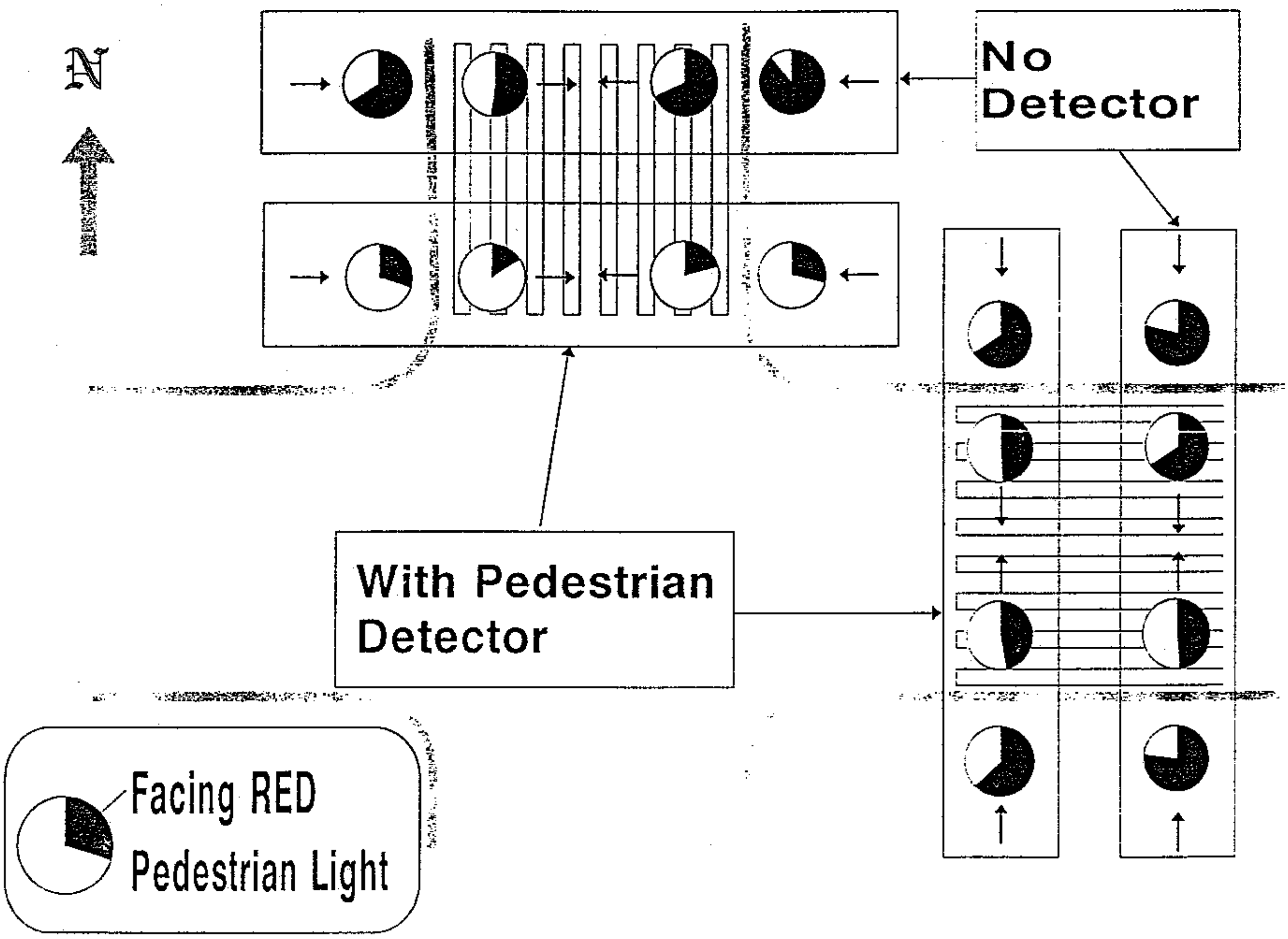


Figure 12: Proportion of Red Arriving and Red Walking Pedestrians with and without Pedestrian Detection

From a safety point of view it is important not only to look at pedestrians walking against red but also to look at pedestrians crossing the road when conflicting cars have a green light. The results indicate a reduction in the frequency of this dangerous situation, but the reduction is of course smaller. The observations revealed that about half of the pedestrians who walked on red did so when the vehicles had green and the other half walked when the vehicle light was changing (see Figure 13).

Another indicator of the safety effect was the expected change in the number of traffic conflicts. Conflict studies were carried out for one week (30 hours) without detectors and the same length of time with detectors. The number of different kind of conflicts can be seen in Table 1.

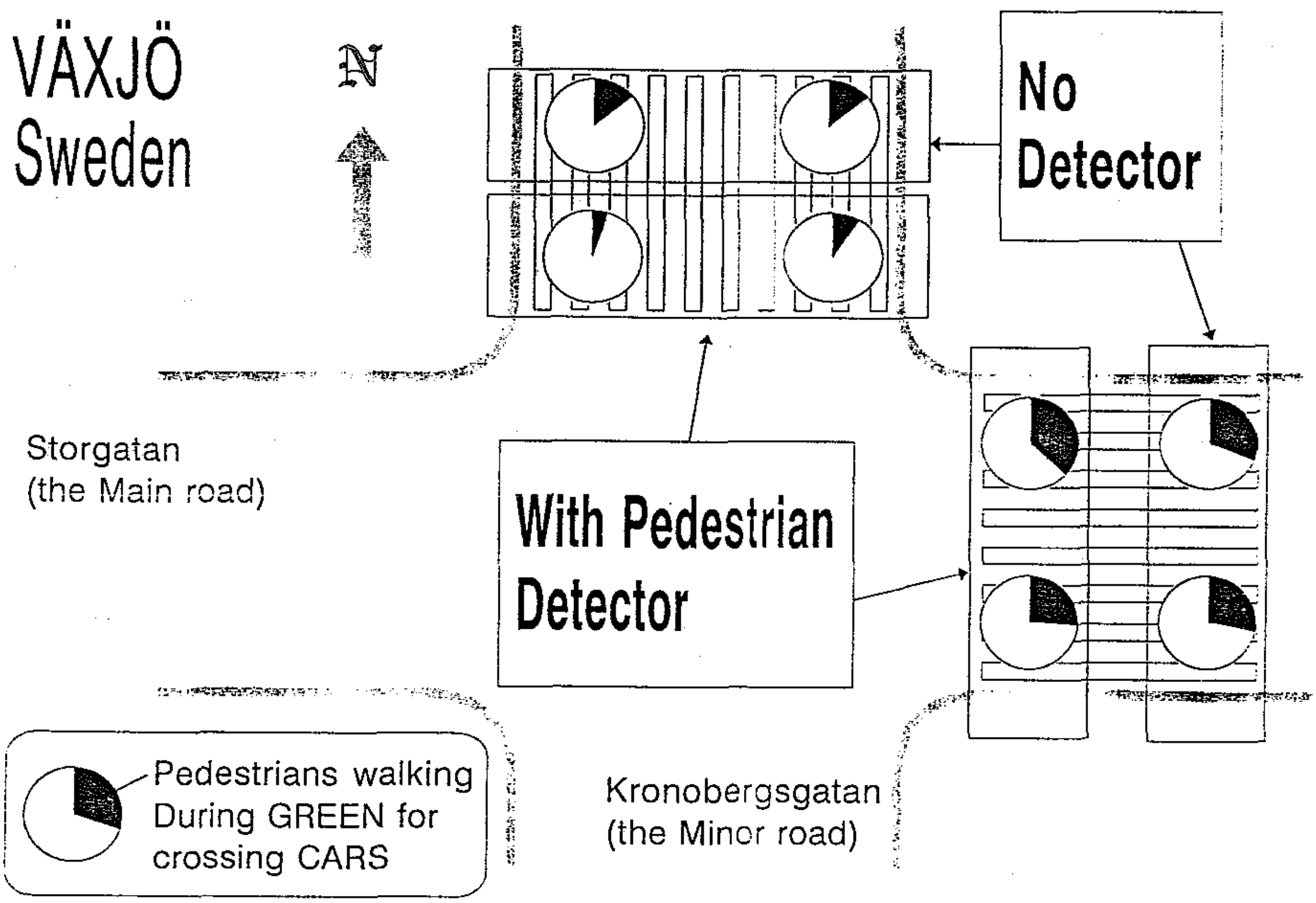


Figure 13: Proportion of Pedestrians who Walk on Red when the Conflicting Traffic has Green with and without Pedestrian Detection

Table 1: Serious conflicts at Växjö junction without and with pedestrian detection

Conflict Type	No Detector	With Detector
Car-pedestrian	6	0
Car-cycle, cycle-cycle	1	2
Car-car	3	1
Total	10	3

The conflict numbers are rather small, but the results show a remarkably large safety effect, especially as far as car-pedestrian conflicts are concerned. The change can, however, be attributed partly to random effects, independent of the experiment. It is worth mentioning that three of the conflicts in the before situation involved cars that violated the red light, and it is highly improbable that the experiment could influence car red light violation, and even more unlikely that it would reduce it.

A conflict diagram from the thirty hours of conflict observation with and without detectors is presented in Figures 14 and 15. It can be seen that the majority of car-pedestrian conflicts in the non-detection situation occurred on the zebra crossing of the minor road.

Mobility effects

The expected mobility effect for pedestrians was a reduction in waiting time and the expected effect of pedestrian detection on vehicles was a slight increase in delay time. If we look only at the change in the length of green time provided for cars and pedestrians, we can then see that green time for cars was not significantly changed by the experiment (see Figure 16).

Pedestrians got far more green time when pedestrian detectors were active (see Figure 17). This indicates an improvement in mobility for pedestrians in general.

As far as individual delay times are concerned, car delay did not seem to be increased — in fact it even showed some decrease as indicated by Figures 18 and 19. This could not be due to the experiment, but might be an effect of some change in the traffic flow of the next intersection to which the signal was linked that occurred during the observation period.

Looking at individual pedestrians, it can be seen that delays less than 10–15 seconds have been reduced by pedestrian detectors. This improvement could be a result of the general increase in green time for pedestrians. Longer pedestrian delays might be attributable to longer queues of crossing cars and also to some persons stopping at the kerb to waiting for something (not traffic) (see Figures 20 and 21).

2.3.4 Discussion and conclusions

The experiment has shown that pedestrians can be efficiently detected even in towns and their detection can be used for directing signal controls. Pedestrian detection

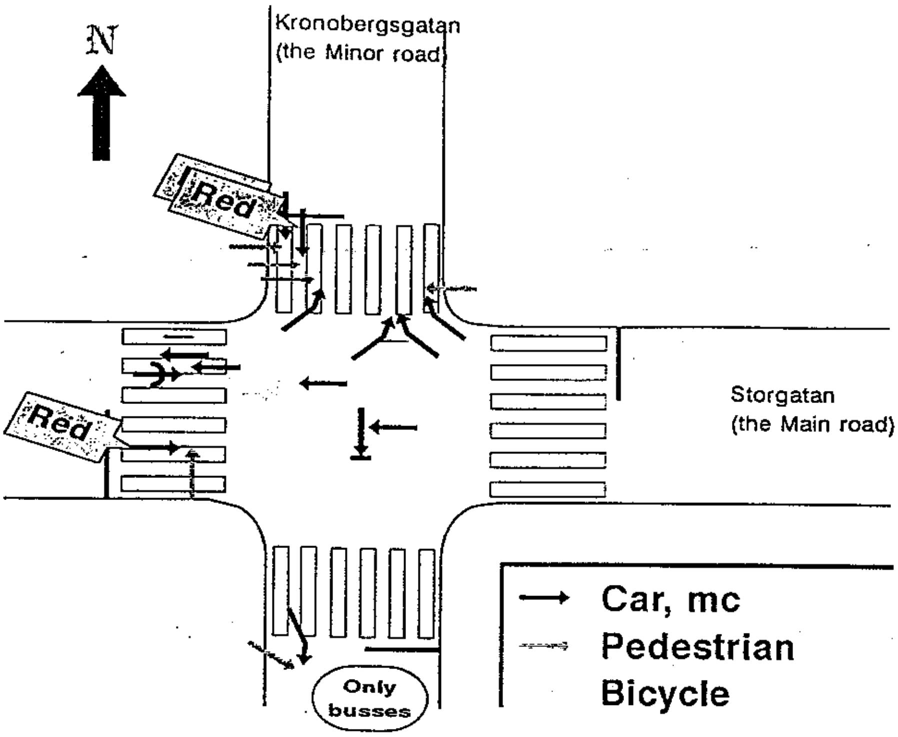


Figure 14: Serious Conflicts at Intersection without Pedestrian Detection

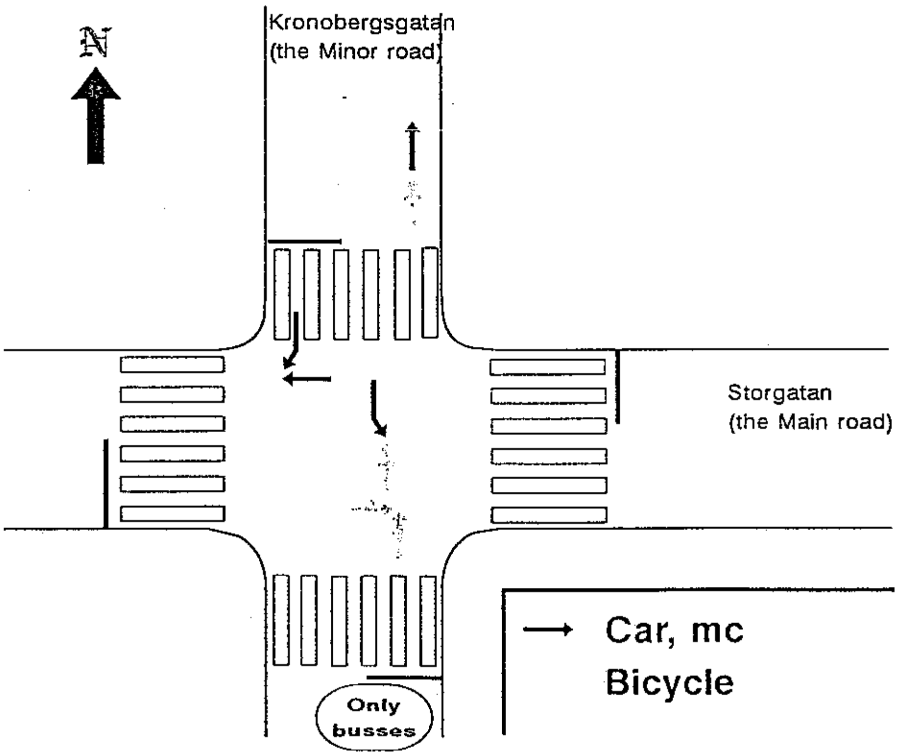
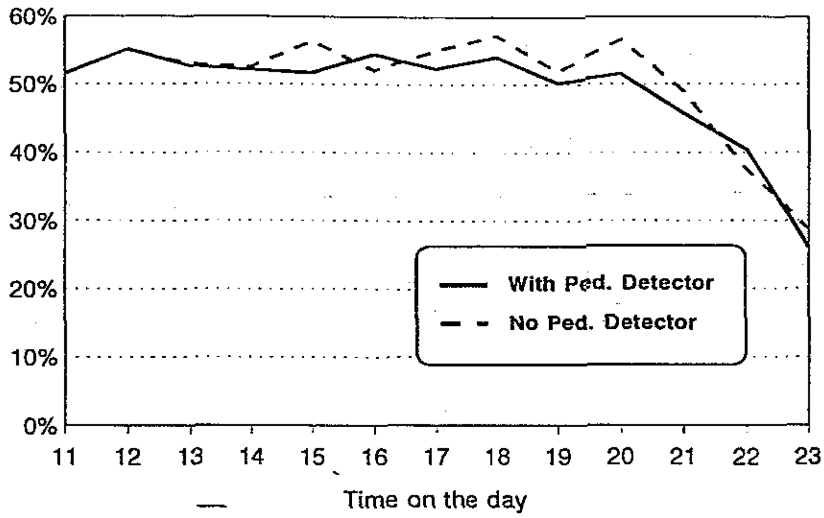
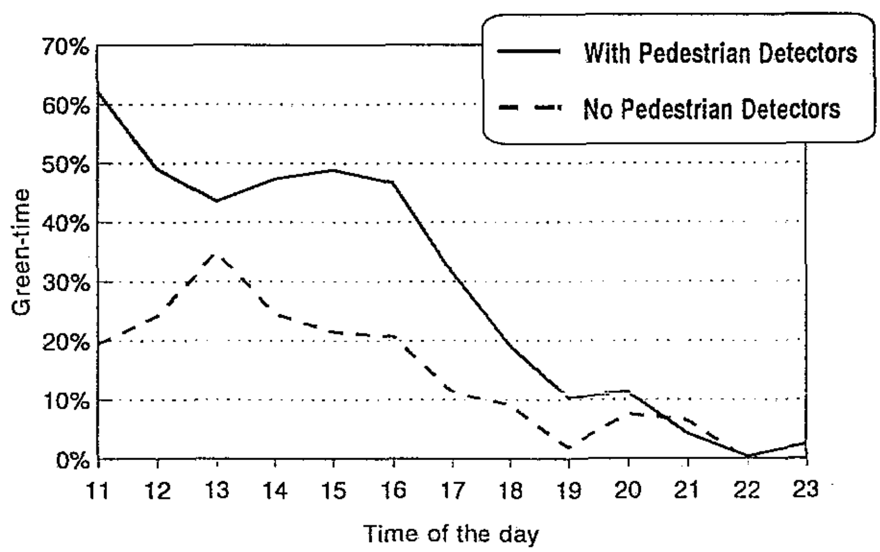


Figure 15: Serious Conflicts at Intersection with Pedestrian Detection



Lars Ekman LTH

Figure 16: Green Time for Cars on the Major Road with and without Pedestrian Detection



Lars Ekman LTH

Figure 17: Green Time for Pedestrians Crossing the Minor Road with and without Pedestrian Detection

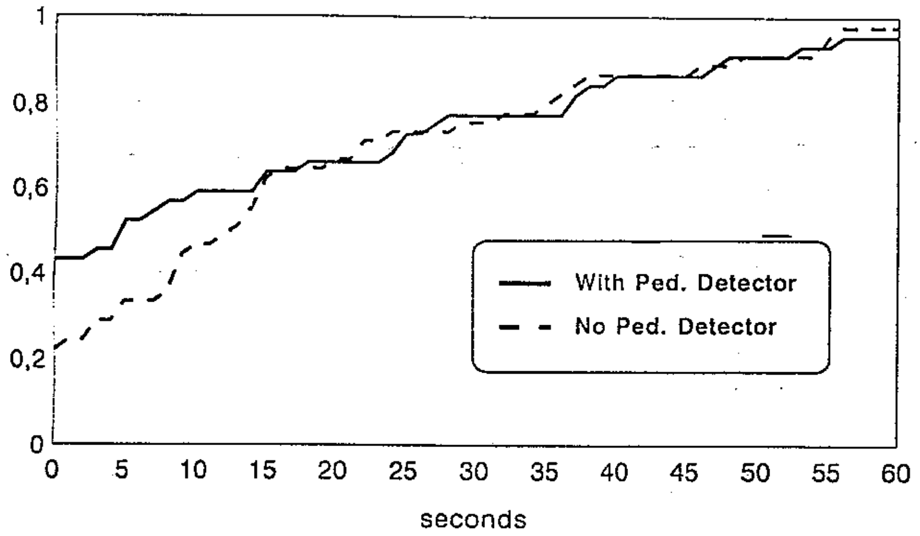


Figure 18: Delay for Cars on the Minor Road with and without Pedestrian Detection

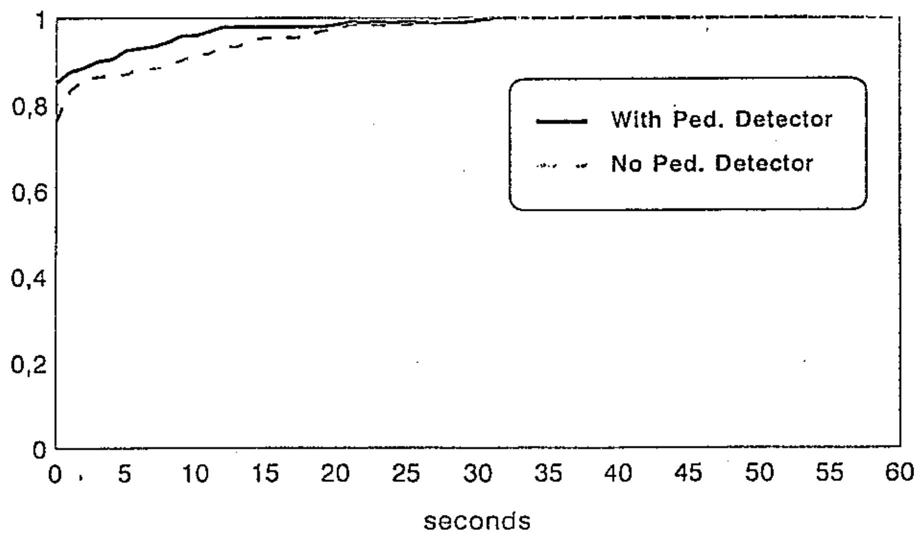


Figure 19: Delay for Cars on the Major Road with and without Pedestrian Detection

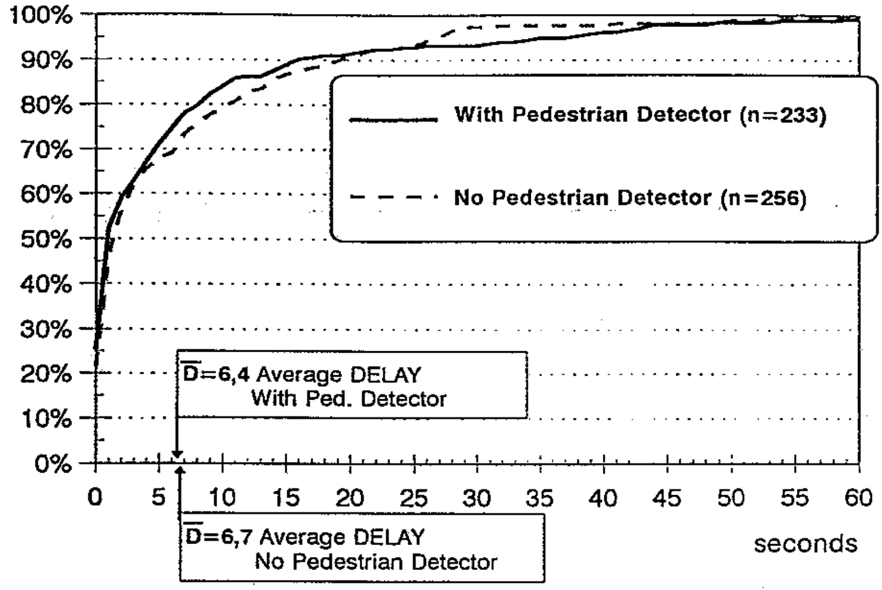


Figure 20: Delay for Pedestrians Crossing the Major Road with and without Pedestrian Detection

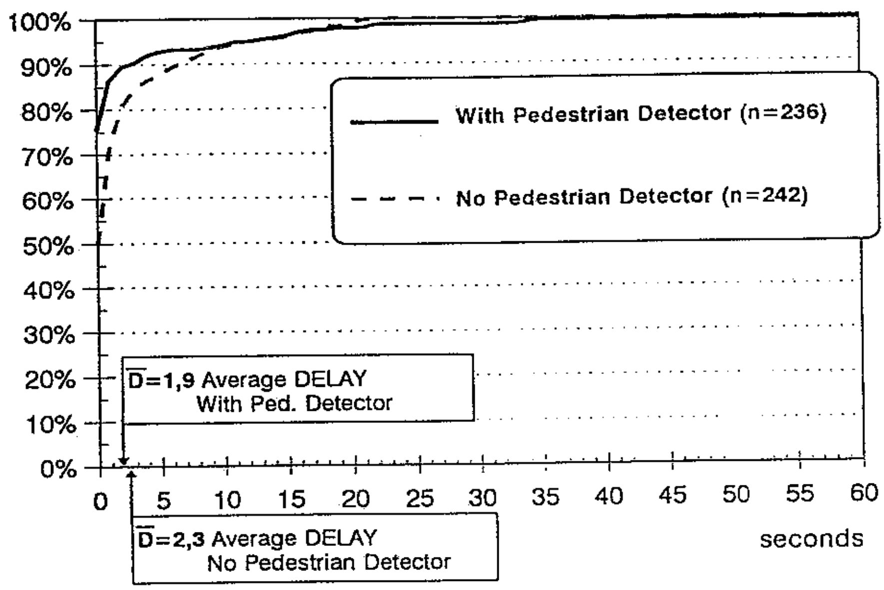


Figure 21: Delay for Pedestrians Crossing the Minor Road with and without Pedestrian Detection

improved pedestrian mobility by increasing green time for pedestrians and decreasing delay, especially as regards the shorter category (shorter than 15 seconds) of delay time. This probably occurred because the signal had already been activated by the detector when the pedestrian approached the crossing, and the pedestrian therefore did not need to wait for the signal to change if there was no conflicting car present. Car mobility was not negatively influenced by pedestrian detection: there was even some reduction in car delay. This cannot, however, be an effect of the intervention but must result from some unknown concurrent event. Since the two effects do not seem to be necessarily conflicting, there might be an opportunity in some cases to improve pedestrian mobility without affecting car mobility adversely.

The effect of pedestrian detection on safety also seemed to be positive. The number of serious conflicts decreased and pedestrian red walking diminished, both in the periods when there was no conflicting car present and when the traffic light for crossing car traffic was green.

2.4 THE GRONINGEN OBSERVATION EXPERIMENT

I.N.L.G. van Schagen, J.M. Spikman and E.J. Westra

2.4.1 Introduction

In the Netherlands pedal cycling is a very important mode of transport. Nowadays, in the light of the increasing concern about the contribution of motor traffic to the air and noise pollution, bicycle traffic is explicitly encouraged, in particular for short trips to and from work and in connection with longer trips by train or public bus. This policy of encouragement involves, among other things, infrastructural measures with the purpose of making cycling more attractive and more safe. In many other European countries too, bicycle traffic is being stimulated and the infrastructure is being adapted to consider the increasing number of cyclists in traffic (e.g., De Wit, 1988).

One of the infrastructural measures for cyclists is the construction of more cycle paths and cycle lanes. A cycle path is physically separated from the main road by a strip of grass or bushes, by car parking places or by poles. Cycle paths are mostly one directional, but occasionally two directional. A cycle lane is a part of the main road, that is reserved for cyclists. The cycle lane is separated from the motor traffic lane by a white dotted or solid line, and the cycle lane is provided with a white painted bicycle symbol and occasionally a coloured surface. A cycle lane is always one directional. In the Netherlands, the use of both cycle paths and cycle lanes is compulsory, not only for bicycles, but also for mopeds (with an engine size of less than 50 cc). Exceptions are the tourist cycle paths (indicated by a special sign) in the country side. These tourist cycle paths are forbidden to moped riders and are optional for cyclists.

The main reason for the construction of cycle paths and cycle lanes is the expected safety benefit. Most cyclist and moped rider casualties result from a collision with motorized traffic and the consequences of such accidents are often serious (Van Schagen and Rothengatter, 1989). Separating the two conflicting flows will help to decrease this type of accidents. However, it is difficult to affirm empirically the expected safety effects. The accident data often lack detailed descriptions of the accident location. In addition exposure data, that specify the use of cycle path facilities and the number of interactions between bicycles/mopeds and motorized traffic, are not available. Welleman (1985) found that, at intersections within built-up areas, 22 percent of the cyclist victims and 25 percent of the moped victims occurred in a situation with a cycle path. At intersections outside built-up areas, these percentages were higher: 36 percent for cyclists and 50 percent for moped riders. Van Schagen anf Rothengatter (1989) report that in 21 percent of the cyclist accidents in the city of Groningen, there was a cycle path or cycle lane facility. Welleman and Dijkstra (1987; 1988) show that for cyclists the overall accident risk (i.e., corrected for estimated traffic flows) is more or less the same with and without cycle path facilities. They found that, on lengths of road and at minor intersections, the number of bicycle accidents decrease by 24 percent with the provision of a cycle path. However, at the same time there is a significant increase of 32 percent in bicycle accidents at intersections with arterial roads, which indicates that accidents have migrated. For moped riders the overall safety effect of cycle-paths is negative: an increase of 28 percent on lengths of road and at minor intersections and an increase of 66 percent at intersections with arterial roads. In other countries too, the possibility of migration of bicycle accidents after the construction of cycle paths is often mentioned (e.g. Smith and Walsh, 1988). It is difficult to compare the effects of cycle paths on the safety of moped riders internationally, because of the various regulations with respect to their legal position in road traffic.

From the safety data, it can be concluded that cycle paths are only partly suitable as a safety improving measure, because accidents tend to migrate to those places where cyclists and moped riders have to interact with motorized traffic, namely to the intersections. Usually, in particular within built-up areas, a parallel cycle path has the same status as the major road. This means that cars approaching the major road not only have to give way to motorized traffic at the main road, but also to cyclists and mopeds at the parallel cycle path. Cars, turning from the main road into the minor road have to give way to traffic on the parallel cycle path as well. Therefore it can be hypothesized, that most car/bicycle accidents at intersections with cycle paths are caused by drivers of motorized vehicles who fail to give way to traffic at the cycle path. Accident statistics lack the required level of detail to verify this hypothesis.

Several reasons can be thought of to explain the failure of drivers to give way to cyclists and moped riders. Visibility, attention and expectations are the key issues here. Cycle paths are often separated from the parallel road by bushes or parked cars. These will block the view for traffic at the parallel road. Drivers of heavy good vehicles have a general problem to see what is driving or riding alongside. When entering a major road with a parallel cycle path, attention must be paid both to traffic on the main road and to traffic on the cycle path. Peripheral vision is an attention directing mechanism. As peripheral vision is more sensitive to bigger and faster moving objects (Wertheim, 1986; Wierda and Aasman, 1991), attention is initially drawn to cars, whereas cyclists and moped riders can be easily overlooked. Attention is also at least partly directed by expectations about the situation. Attention is given to the direction from which traffic might approach (Wierda and Aasman, 1991). In the case of a two-directional cycle path, traffic is primarily expected from and attention is primarily given to the "normal" direction. Mopeds on the cycle path form an additional problem, because of their speed. In the Netherlands, the legal speed limit for mopeds is 30 km/h inside and 40 km/h outside built-up areas. The actual speeds are often much higher (Wierda et al., 1989). As the majority of the traffic on the cycle path are cyclists, with an average speed of 16 km/h (Brookhuis et al., 1986), car drivers are probably inclined to look in the direct neighbourhood of the intersection. At the moment of visual search, an approaching moped may not yet be in the field of view, whereas at the moment the car driver actually crosses the cycle path, it may already be within conflict distance.

To get more information on the causes of the unsafety of cycle paths at intersections, an observation experiment was carried out at an intersection with a two-directional cycle path in the city of Groningen, the Netherlands. This intersection was chosen because of its known safety problem. As such it cannot be considered as a representative sample of cycle paths. However, because of its unsafety, it was possible to analyze enough examples of accident related behaviour. Several aspects of the interaction between cyclists and moped riders on the cycle path and motorized traffic were studied: number and type of conflicts, priority behaviour of car drivers, resulting delays for cyclists and moped riders and visual search strategies of car drivers. In the next section the physical and traffic characteristics of the observation site are described. Section 2.4.3 gives an overview of the data collection procedure for the various variables and Section 2.4.4 presents the results. The conclusions are presented in Section 2.4.5, together with a discussion on possible solutions.

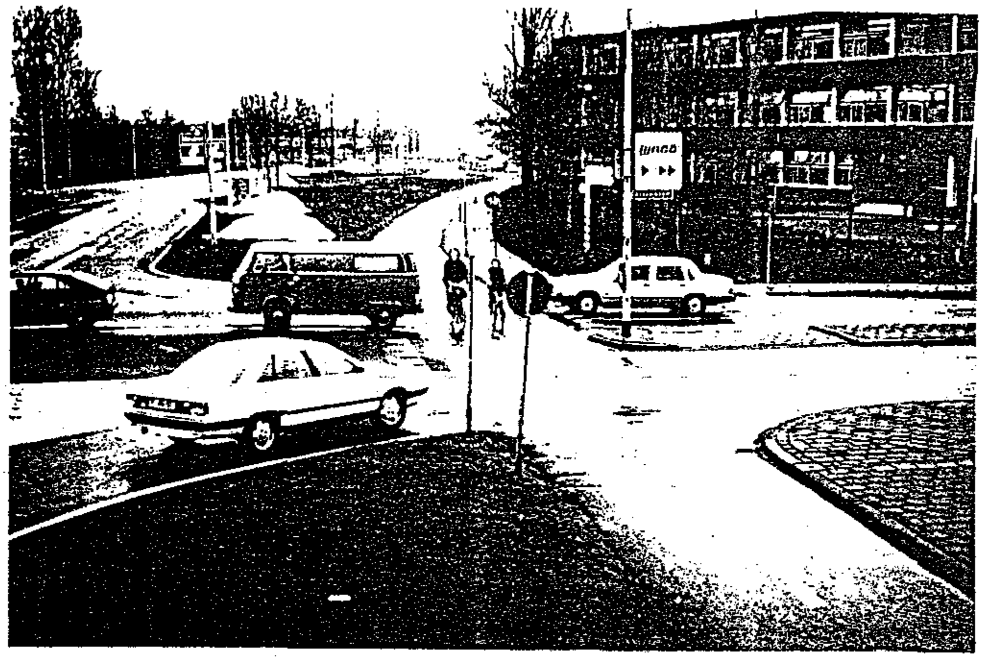


Figure 22: The Observation Site

2.4.2 Description of the observation site

The observation site is located near the outer ring road, west of the city of Groningen. It is a four armed junction. A picture of this location is shown in Figure 22.

The main road (Hoendiep), going in east-west direction, is a dual carriageway. Parallel to the northern lane is a two-directional cycle path. The side roads (Atoomweg) give entrance to some light industries and large shops and garages. Both motor and cycling traffic consists mainly of commuters, travelling from nearby villages to work or school in the city of Groningen or from the villages and the city to offices in the industrial area. Additional traffic consists of customers and suppliers of the industries, shops and garages. The intersection is part of the route for the practical driver's license examination, resulting in relatively many learner drivers. It can be concluded that the majority of the passing traffic is familiar with the traffic situation.

The priority at the intersection is regulated by traffic signs and mmarkings. Traffic on the main road has priority over traffic on the side roads. The cycle path is considered as part of the main road, which means that cyclists and moped riders also have priority over traffic on the side road. Motorized traffic turning from the main road into the side road has to give way to cyclists and mopeds on the cycle path, because of the general rule that turning traffic has to give priority to traffic going straight ahead on the same road. This means that in all situations motorized traffic has to give way to bicycles and mopeds on the cycle path.

2.4.3 Variables and observation method

Data was collected on traffic flows, number and type of conflicts, looking behaviour of drivers and the characteristics of the bicycle/car interactions (rule compliance and delays). All observations took place in one week on a Tuesday, Wednesday and Thursday in January. Weather conditions were reasonable for that time of the year with no rain or snow, moderate wind and temperatures around 6 degrees Celsius.

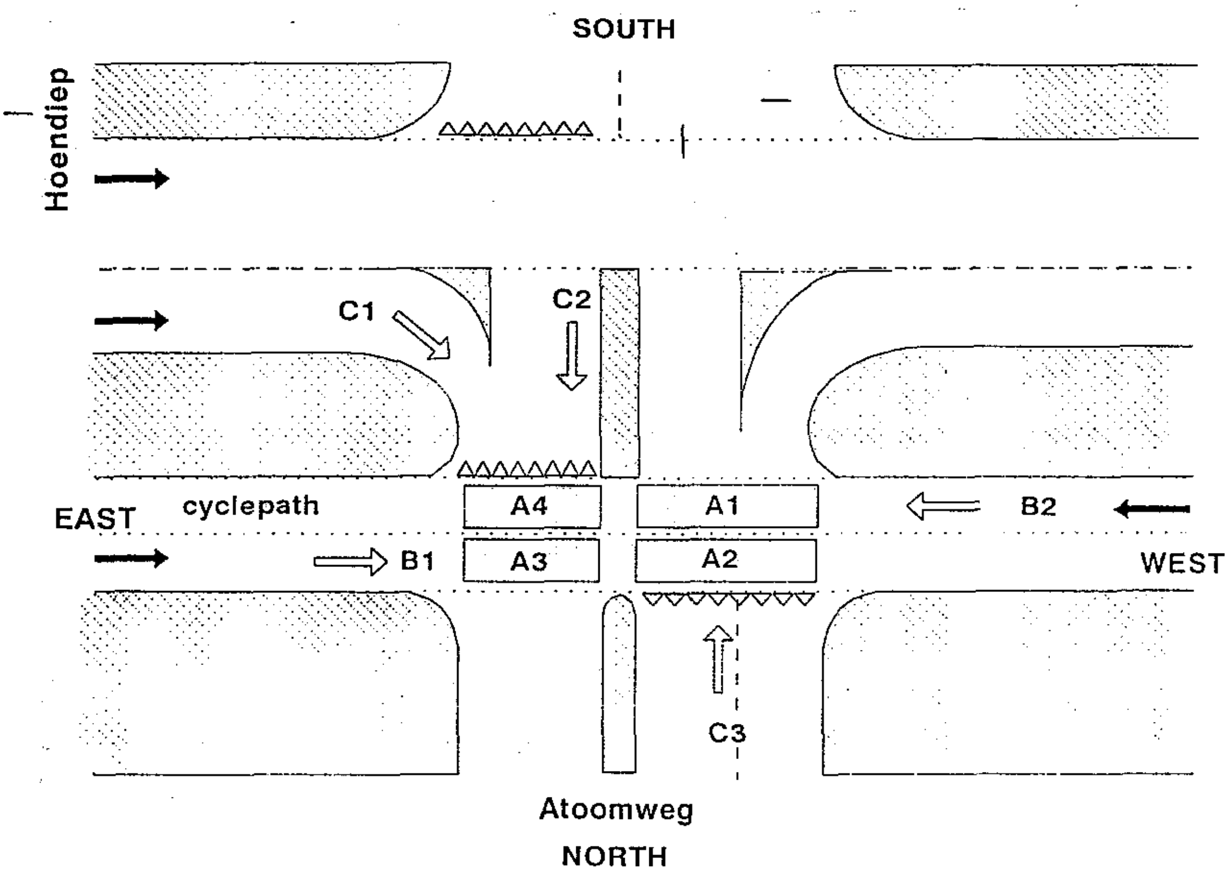


Figure 23: Schematic Drawing of the Observation Site Showing Approach and Encounter Areas

The observations were limited to the northern half of the intersection (see Figure 23). This part of the intersection was split into 9 smaller sections to distinguish between the different type of interactions. Sections A1 to A4 represent the bicycle/car encounter areas. Section B1 is the approach area of cyclists and moped riders travelling from east to west;

section B2 is the approach direction of cyclists and moped riders travelling in the opposite direction. Section C1 is the approach area of motorized traffic on the main road, coming from the east side and turning right; section C2 is the approach area of motorized traffic coming from the west side and turning left or coming from the south and going straight on; and section C3 is the approach area of motorized traffic from the northern side road. Six types of bicycle/car interactions are possible: cyclists from two directions and cars from three directions.

Traffic volumes

An indication of the traffic volumes is based on 4.5 hours of video recording on Tuesday afternoon between 12.00 and 4.30. For each category of road user (bicycle, moped, private car, track/van/bus) the averages per hour per approach area were computed.

Number and type of conflicts

The number and type of conflicts were determined according to the Swedish Conflict Technique (Hydén, 1987). Conflicts were observed and recorded on the spot by two trained observers for a total period of 15 hours. The study covers situations between 9 a.m. and 5 p.m.

Priority behaviour of car drivers

At the observation site, signs indicate that all motorized traffic must give way to the cyclists and moped riders on the cycle path. An analysis was made of whether car drivers generally complied with this rule and whether there were differences in rule compliance percentages between the four encounter areas A1 to A4. Car drivers who did not or seemed not to comply to the rule might cause delay to cyclists and moped riders. For each of the encounter areas, an assessment was made of how often a cyclist or moped rider was delayed by motorized traffic that crossed the cycle path.

Priority behaviour is of course only relevant when there is an encounter between road users. To determine whether there was an encounter or not the Post Encroachment Time (PET) was measured. PET refers to the interval between the moment that one road user passes out of the area of potential collision and the moment of arrival at the potential collision area by a second road user (Cooper, 1984). PET was measured with a stopwatch and registered in integers. When PET was 5 seconds or less this was defined as an encounter situation (Janssen and Van der Horst, 1988). If, in an encounter, one or both road users involved changed speed and/or course, this was called an interaction.

Video recordings were made on Tuesday, Wednesday and Thursday afternoon from 12.00 until 4.30. A total of 13 hours of video were available, and were analyzed afterwards. Encounter data were recorded for each of the four encounter areas (A1 – A4). Only encounters with cyclists or moped riders approaching from section B1 or B2 were studied. Each cyclist or moped rider could have several encounters: when crossing the first half of the intersection (A1 or A3) and when crossing the second half (A4 or A2). It is also possible that a bicycle or moped had more than one encounter on a road section (e.g., when one car passes with a PET smaller than 5 seconds, a second car may arrive before the bicycle or moped has arrived). In that case both encounters were taken into account.

The following data were coded from video:

- The number of cyclists passing each of the encounter areas without encounter
- The number of bicycle/car encounters (PET $\leq$ 5 sec.) per section A1–A4

In case of a bicycle/car encounter:

- Whether or not the cyclist passed before the car

If the bicycle passed before the car, four types of situations were distinguished:

a. Neither the cyclist nor the car driver slowed down (in case of a large PET)
b. The car slowed down and gave priority, the cyclist did not slow down
c. The car slowed down and gave priority, the cyclist did slow down
d. The car slowed down and gave priority, the cyclist made a swerving movement (probably in anticipation of a priority failure)

If the car crossed before the bicycle, four further types of situations were distinguished:

d. Neither the cyclist nor the car driver slowed down (in case of a large PET)
e. The cyclist slowed down
f. The cyclist made a swerving movement
g. The cyclist stopped

The number of cyclists who were delayed by motorized traffic crossing the cycle path was computed by adding up the numbers of cyclists who slowed down or made a swerving movement. No distinction was made between who eventually passed first.

<u>Looking behaviour of drivers</u>

The looking behaviour was assessed by observing the head movements of car drivers approaching the intersection. Car drivers coming from the northern or southern direction (section C3 and C2) must move their heads to be able look for traffic on the cycle path. Car drivers coming from the east and turning right (section C1) have to look over their right-hand shoulder to see whether a cyclist or moped rider approaches from that direction. They also should look to the west to see whether a cyclist or moped is approaching from that direction. However, in this case the car driver does not necessarily have to move his head. He might have looked before making the right turn. It should be borne in mind that head movements are an approximation of looking behaviour. In case of car driver in section C2 or C3, a head movement means that the driver *could have seen* traffic at the cycle path, but not that he *really saw* it. This also applies to a car driver in section C1, who turns his head to the right. However, the absence of head movements to the left of this car driver does not mean that he could not have seen bicycles or mopeds from that direction.

The head movement observations took place on Tuesday, Wednesday and Thursday between 12.00 and 4.30 in the afternoon. The total observation time was 10 hours. The observations were carried out on the spot by two observers. The observers were seated in a car parked close to the intersection. One of the observers recorded the data on traffic from directions C1 and C2, the other observer the data on traffic from direction C3. Because traffic flows were sometimes high, it was not possible to observe every car. In that case the first approaching car was observed and when all data were filled in on the observation form, the next car to arrive was observed.

The following data were filled in on the observation form:
- Type of car (private car/truck, van or bus)
- Approach section of car (C1, C2 or C3)
- Head movements of driver or front seat passenger towards B1 (yes/no/indefinite)
- Head movements of driver or front seat passenger towards B2 (yes/no/indefinite)

The category "indefinite" was used when the observer could not reliably see the head movements.

If a two-wheeler approached, the following data were added:
- PET (in integers)
- Type of two-wheeler (cyclist/moped rider)
- Approaching section of the two-wheeler (B1 or B2)
- Characteristics of priority behaviour (which road user passed before the other, did one (or both) road user(s) decelerate).

2.4.4 Results

<u>Traffic volumes</u>

The average traffic flows per hour approaching the intersection from various directions, are shown in Tables 2 (motorized vehicles) and 3 (bicycles/mopeds).

Table 2: Car flows per hour by approach section

	Approach Section		
Car type	East, turn right (C1)	South (C2)	North (C3)
Passenger car	158	16	214
Van/truck/bus	54	5	51
Motor-cycle	3	0	4
Total	215	21	269

Table 3: Two-wheeler flows per hour by approach section

	Approach Section	
Type of two-wheeler	East (B1)	West (B2)
Bicycle	95	85
Moped	8	6
Total	103	91

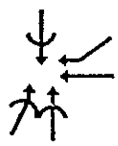
Because the Dutch department for driving licenses was located in the close neighbourhood of the intersection, a rather large part of the flow consisted of learner drivers (approximately 13% of the motorized vehicles).

Approximately one quarter of the cars, that cross the cycle path have an encounter with a bicycle or moped (PET ≤ 5 sec.). Of these cars, one third pass before the cyclist or moped rider, the others pass behind the cyclist or moped rider.

Conflicts

A total of 31 conflicts were observed, half of which must be categorized as serious conflicts, based on the TA/speed trade-off. All observed conflicts were conflicts between a two-wheeler and a motorized vehicle. Figure 24 presents the type and number of the serious and slight conflicts.

It appears that in 15 of the 16 serious conflicts and in 10 of the 15 slight conflicts a car approaches from the north (C3), generally preparing for a left turning movement. As flows from this direction are only slightly higher than from the opposite direction, this cannot explain the results. Excluding the "rest" category, it appears that in 14 of the 15 serious conflicts and in 9 of the 10 slight conflicts the bicycle/moped approaches from the west (B2), that is the "unexpected" direction. Again flow cannot be an explanatory factor. The similarity of patterns of the serious conflicts can be seen in Figure 25.

Type		Serious Conflicts	Slight Conflicts
Car-Bicycle		10*	8
Car-Moped		3	0
Car-Bicycle		0	1
Car-Bicycle		1	1
Car-Bicycle		1	0
Car-Bicycle (the rest)		1	5

* One accident with minor personal injury

Figure 24: Number and Type of Serious and Slight Conflicts

Three mopeds were involved in a serious conflict as compared to 13 bicycles. When taking into account the flow data, which show that there are approximately 12 times more cyclists than moped riders, it can be concluded that mopeds are overrepresented in the serious conflicts.

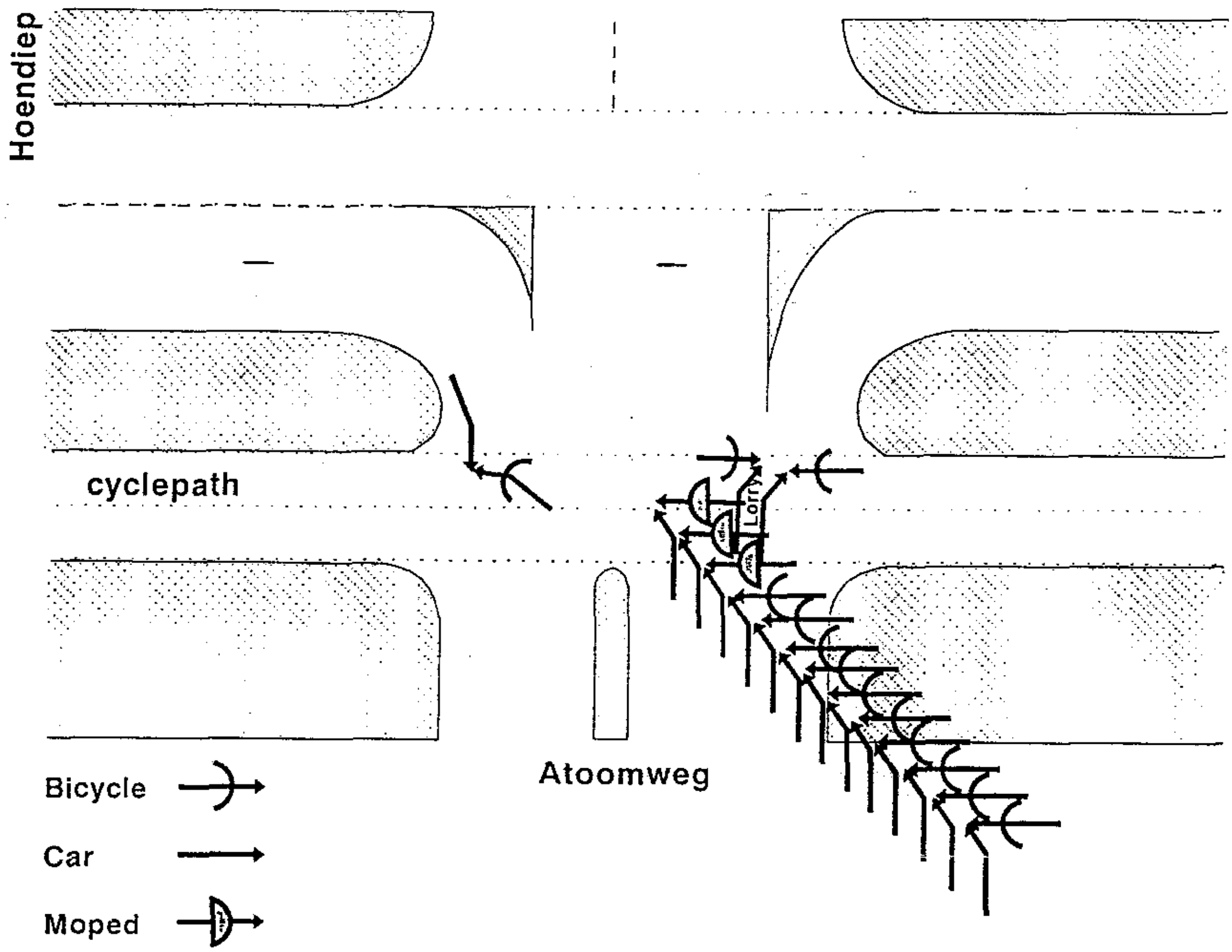


Figure 25: Overview of the Pattern of Serious Conflicts

Priority behaviour of car drivers towards cyclists

A total of 2520 encounters between a bicycle and a motorized vehicle were analyzed. The number of encounters is not equal to the number of cyclists who had an encounter, because a cyclist could have several encounters in the same encounter area. The number of cyclists who passed an encounter area without meeting a car was 442 (A1), 429 (A2), 657 (A3) and 640 (A4). The encounters were analyzed for each of the encounter areas separately. In encounter areas A1 and A2, the car approached from the side road (C3); in encounter areas A3 and A4, the car approached either from the south (C2) or from the east and turned right (C1).

In Table 4 the car/bicycle encounters are split into those in which the cyclist passes before the car and those in which the car passes before the cyclist.

Table 4: Car/bicycle encounters by encounter type and encounter area

Encounter Area	Order of Passage: Bicycle First N (%)	Car First N (%)	Total N (%)
A1	533 (73.3%)	194 (26.7%)	727 (100%)
A2	655 (87.5%)	93 (12.5%)	748 (100%)
A3	496 (89.5%)	58 (10.5%)	554 (100%)
A4	366 (74.5%	125 (25.5%)	491 (100%)
All	2050 (81.3%)	470 (18.7%)	2520 (100%)

The results show, that in approximately 20 percent of the encounters (PET ≤ 5 sec.) the car passes the area before the bicycle. When bicycles approach from the west (B2), that is the unexpected direction, more cars pass first in case of an encounter. This applies in the same proportion whether cars approaching from the side road (C3) or from the main road (C1/C2). An encounter was defined as a PET of 5 seconds or less. If a car passes before a cyclist with a PET of 4 or 5 seconds, he probably did not hinderthe cyclist and hence one cannot speak of a priority mistake. On the other hand it might be that a cyclist passes before a car, but that he slowed down to become sure that he really gets priority. Therefore the encounters were analyzed further in terms of behaviour. Table 5 presents data on the encounters in which the cyclist passed before the car.

Table 5: Behaviour in encounters in which cyclist passes before car by encounter area

Encounter Area	Behaviour: No speed reduction	Car slows down	Both slow down	Cyclist swerves	Total
A1	96 (18.0%)	397 (74.5%)	13 (2.4%)	27 (5.1%)	533 (100%)
A2	55 (8.4%)	583 (89.0%)	2 (0.3%)	15 (2.3%)	655 (100%)
A3	88 (17.7%)	400 (80.6%)	3 (0.6%)	5 (1.1%)	496 (100%)
A4	125 (34.1%)	214 (58.5%)	7 (1.9%)	20 (5.5%)	366 (100%)
All	364 (17.7%)	1594 (77.7%)	25 (1.2%)	67 (3.3%)	2050 (100%)

In almost 20 percent of the encounters, none of the road users involved showed any observable speed reduction, which means that there was no interaction and no question of priority. In almost 5 percent of the encounters the bicycle either slowed down before moving on or he made a swerving movement to pass before the car. Cyclists from the unexpected direction (B2) more often slowed down or swerved than cyclists form the other direction (B1).

Table 6 gives the same type of data for encounters in which the car passed before the bicycle.

Table 6: Behaviour in encounters in which the car passes before the cyclist by encounter area

	Behaviour				
Encounter Area	No speed reduction	Cyclist slows down	Cyclist stops	Cyclist swerves	Total
A1	126 (64.9%)	42 (21.6%)	5 (2.6%)	21 (10.8%)	194 (100%)
A2	79 (84.9%)	8 (8.6%)	0 (0.0%)	6 (6.5%)	93 (100%)
A3	43 (74.1%)	15 (25.9%)	0 (0.0%)	0 (0.0%)	58 (100%)
A4	98 (78.4%)	22 (17.6%)	2 (1.6%)	3 (2.4%)	125 (100%)
All	346 (73.6%)	87 (18.5%)	7 (1.5%)	30 (6.4%)	470 (100%)

In almost three quarters of the encounters, in which the car passed before the cyclist, neither the car nor the cyclist had to reduce speed. In the other cases the cyclist was hindered even though he had priority. The cyclist either slowed down to let the car pass, or made a swerving movement to pass just after the car, or stopped to let the car pass. Stopping and swerving were most common for cyclists who approached from the west (B2), the unexpected direction.

Table 7 gives the number of encounters in which a cyclist was delayed, because he either slowed down or made a swerving movement. This was the case in encounters where the bicycle passed before the car and in situations where the car passed before the bicycle. Both type of encounters are combined in the table.

Table 7: Delay in car-cyclist encounters by encounter area

Encounter Area	Delay for cyclist	No delay for cyclist	Total
A1	108 (14.9%)	619 (85.1%)	727 (100%)
A2	31 (4.1%)	717 (95.9%)	748 (100%)
A3	23 (4.2%)	531 (95.8%)	554 (100%)
A4	54 (11.0%)	437 (89.0%)	491 (100%)
All	216 (8.6%)	2304 (91.4%)	2520 (100%)

In almost 9 percent of the encounters the cyclist experienced a delay. Cycle traffic approaching from the west (B2) was more often obliged to reduce speed, to swerve to avoid a conflict or to anticipate the behaviour of car drivers than was cycle traffic from the east (B1).

Priority behaviour of car drivers towards moped riders

A total of 154 encounters between a moped and a motorized vehicle were analyzed. The number of mopeds that did not have an encounter when passing the encounter area was 40 (A1), 50 (A2), 75 (A3) and 54 (A4).

Table 8 gives the results on the order of passage. In a quarter of the encounters the car passed before the moped. This occurred more often when the moped approached from the unexpected direction (B2).

Table 8: Order of passage for car-moped encounters by encounter area

	Order of Passage		
Encounter Area	Moped First	Car First	Total
A1	35 (62.5%)	21 (37.5%)	56 (100%)
A2	42 (95.5%)	2 (4.5%)	44 (100%)
A3	16 (84.2%)	3 (15.8%)	19 (100%)
A4	24 (68.6%)	11 (31.4%)	35 (100%)
All	117 (76.0%)	37 (24.0%)	154 (100%)

In cases where the moped passed the encounter area before the car (Table 9), the car driver normally reduced his speed. The moped rider never reduced his speed, at least not in an observable way. In a few cases the moped made a swerving movement to pass just in front of the car. In half of the cases where the car passed in front of the moped (Table 10), neither the car nor the moped reduced its speed. In the other half of the cases the moped took some reaction, predominantly consisting of a speed reduction.

Table 9: Behaviour in encounters in which the moped passed before car by encounter area

Encounter Area	Behaviour: No speed reduction	Car slows down	Both slow down	Moped swerves	Total
A1	4 (11.4%)	29 (82.9%)	0	2 (5.7%)	35 (100%)
A2	4 (9.5%)	37 (88.1%)	0	1 (2.4%)	42 (100%)
A3	5 (31.3%)	11 (68.7%)	0	0	16 (100%)
A4	2 (8.3%)	18 (75.0%)	0	4 (16.7%)	24 (100%)
All	15 (12.8%)	95 (81.2%)	0	7 (6.0%)	117 (100%)

Table 10: Behaviour in encounters in which the car passes before the moped by encounter area

Encounter Area	Behaviour: No speed reduction	Moped slows down	Moped stops	Moped swerves	Total
A1	7 (33.3%)	11 (52.4%)	2 (9.5%)	1 (4.8%)	21 (100%)
A2	2(100.0%)	0	0	0	2 (100%)
A3	2 (66.7%)	1 (33.3%)	0	0	3 (100%)
A4	7 (63.6%)	4 (36.4%)	0	0	11 (100%)
All	18 (48.6%)	16 (43.2%)	2 (5.4%)	1 (2.7%)	37 (100%)

From Table 11 it can be concluded that the behaviour of car drivers caused a delay to moped riders (slowing down, swerving or stopping) in more than 15 percent of the encounters. Mopeds from the unexpected direction (B2) were delayed more often.

Table 11: Delay in car-moped encounters by encounter area

Encounter Area	Delay for moped	No delay for moped	Total
A1	16 (28.6%)	40 (71.6%)	56 (100%)
A2	1 (2.3%)	43 (97.7%)	44 (100%)
A3	1 (5.2%)	18 (94.8%)	19 (100%)
A4	8 (22.9%)	27 (77.1%)	35 (100%)
All	26 (16.9%)	128 (83.1%)	154 (100%)

Head movements of car drivers

During the ten hours of investigation, a total of 2155 observations were made. Given a flow of 505 vehicles per hour summed up over the three directions, the observed sample comes to 43 percent of the total flow.

Tables 12 and 13 show the results of the observed head movements of the car drivers approaching from the three distinguished directions (C1–C3) before crossing the cycle path. In Table 12 the number of head movements towards the eastern approach area (B1) are presented, with Table 13 showing the comparable numbers towards the western approach area (B2). It was particularly difficult to determine the head movements of van and truck drivers, who approached from the east side and turned right (C1).

Table 12: Numbers and percentages of car drivers making head movements towards the east side of the cycle path (B1)

Approach area of motorized vehicles	Head movement Yes	 No	 Indefinite	 Total
East, turn right (C1)	629 (70.9%)	121 (13.6%)	138 (15.4%)	888 (100%)
South (C2)	43 (62.3%)	26 (37.7%)	0 (0.0%)	69 (100%)
North (C3)	1098 (91.7%)	98 (8.2%)	2 (0.2%)	1198 (100%)
All	1770 (82.2%)	245 (11.4%)	139 (6.5%)	2155 (100%)

Table 13: Numbers and percentages of car drivers making head movements towards the west side of the cycle path (B2)

Approach area of motorized vehicles	Head movement Yes	 No	 Indefinite	 Total
East, turn right (C1)	249 (28.1%)	442 (49.8%)	197 (22.1%)	888 (100%)
South (C2)	30 (43.5%)	38 (55.1%)	1 (1.4%)	69 (100%)
North (C3)	760 (63.5%)	435 (36.3%)	2 (0.2%)	1198 (100%)
All	1039 (48.3%)	915 (42.5%)	199 (9.2%)	2155 (100%)

The data show, that the majority of car drivers turned their heads towards the west before crossing the cycle path. This is the "normal" direction from which cyclists and moped riders are expected. Less than half of the car drivers turned their heads in the other direction, that is the direction from which no traffic is normally expected. Car drivers coming from the north (C3) had more head movements than car drivers from the other directions (C1 and C2).

Because a relatively large proportion of the car flow consisted of learner cars (13%), the looking behaviour of learner drivers was compared to that of other drivers. It appeared that learner drivers made significantly more head movements than other drivers (Chi-square=20.5, $p<.001$ for head movements to the east side (B1) and Chi-square=40.4, $p<.001$ for head movements to the west side (B2)). This means that the average percentages of car drivers who made head movements, as presented in Tables 12 and 13 might be an overestimation of the behaviour of the average driver population.

2.4.5 Discussion and conclusions

The results clearly show that there is a severe safety problem for cyclists and moped riders in this situation. The problem is mainly caused by motorized traffic approaching the cycle path from the side road. This traffic comes into conflict with cyclists and moped riders who approach from the right side, i.e. the direction that might normally be expected to ride on the opposite side of the road. Most car drivers who come into conflict with cycle traffic are preparing to make a left turn into the main road. However, the flows by turning movement are not known, so that it is difficult to conclude whether the left turn is related to the number of conflicts or whether the majority of cars make this turning movement. Taking into account the number of bicycles and mopeds approaching the intersection, the probability of coming into a serious conflict with a car is higher for moped riders than for cyclists.

At the observation site, in all encounters between motorized traffic and cycle traffic on the cycle path, the latter group officially has priority. It can therefore be concluded that the conflicts are caused by car drivers who fail to give way. In almost 20 percent of the bicycle/car encounters and in approximately 25 percent of the moped/car encounters, the car passes the cycle path without waiting for the bicycle or moped. This behaviour by the car drivers generates a reaction (slowing down, stopping or swerving) on the part of the cyclist in a quarter of the cases and of the moped riders in half of the cases. A car passes before a cyclist or moped rider more often if these approach from the unexpected direction. Even if a car eventually gives way to traffic at the cycle path, the cyclist or moped rider sometimes (5%) first reduces speed or makes a swerving movement, probably in anticipation of the car behaviour. Cyclists and moped riders who approach from the unexpected direction more often show this anticipative behaviour and are more often delayed than those approaching from the other direction.

The looking behaviour of car drivers, as deduced from the observed head movements, seems insufficient. On the average, 80 percent of the car drivers were positively identified as moving their heads to the side from which cycle traffic is normally expected, whereas only half of the car drivers move their head towards the other side. The cause of the most of the problems is motorized traffic that approaches from the side road. These drivers move their head more often than the other drivers. In the first instance this seems contradictory. However, an explanation might be that these drivers move their head to look for motorized traffic on the major road, which they have to cross, and not to look for traffic on the cycle path. Traffic from the other directions, on the other hand, only has to cross the cycle path at the moment of observation and head movements at that time will almost certainly be directed to traffic on the cycle path.

The behaviour of car drivers towards encountered cyclists and moped riders and, more generally, the head movements of car drivers indicate that car drivers do not adequately consider the possibility of cycle traffic approaching from the unexpected direction. As most traffic must be rather familiar with this particular situation, a lack of knowledge can only be part of the explanation. Another explanation might be that looking for traffic at intersections is a rather automatic procedure, developed on the basis of numerous experiences. As cycle paths are only occasionally two-directional, looking to the other than the normal direction might not be incorporated in the automatic looking sequences.

To decrease the safety problem in this type of situation, solutions should be directed to measures that increase the level of attention of car drivers. If they are unfamiliar with the situation, this will make them aware of the special features of the intersection and if they are familiar with the situation, it will interrupt their automatic behaviour sequences.

The present situation at the observation site is that the two-directional cycle path is indicated by a normal traffic sign for a cycle crossing place with an additional sign beneath it shwing two arrows pointing to the left and the right. This is supposed to indicate that bicycles and mopeds may approach from both directions. However, these signs are small and inconspicuous and therefore not suitable for increasing the driver's level of attention.

A relatively simple infrastructural solution is to raise the cycle path, where it crosses the intersection. This results in a ramp for motorized vehicles. Motorists approaching the cycle path have to slow down to pass the ramp comfortably. In this way the presence of a cycle path will be made more salient, although the fact that it is a two-directional cycle path is not particularly emphasized. However, because of the reduced speed, motorized traffic has more time to oversee the situation and to actively look for approaching cyclists or mopeds in both directions. Ramps are often thought to be less suitable for locations with a heavy flow of HGVs, as is the case here.

Another possibility is a flashing warning signal in combination with a traffic sign depicting informing the driver of the two-directional cycle path. Such a signal might increase the level of attention, particularly for drivers who are unfamiliar with the situation. The signal would make it clear that the traffic situation deviates from the norm and is potentially threatening. It must be doubted, however, whether this attention increasing function would remain for people who pass the location regularly. A traffic activated, or intelligent warning system may prevent such habituation to the flashing warning signal. Here the warning light would only flash if a cyclist or moped actually were approaching the intersection.

An intelligent warning system requires that the presence of cyclists and mopeds on the cycle path be reliably detected. In addition the direction and the speed of the approaching cycle traffic must be known. There are several ways to realize this type of detection, but a pair of detection loops from which both direction and speed can be deduced seems most suitable for this application. From the direction and speed information it can be calculated at what time the cyclist or moped will arrive at the intersection. A few seconds before their arrival, the warning signals must be switched on to draw the attention of the car drivers to the presence of the cycle traffic. In principle, it is possible to compute the time when the cyclist or moped will have left the intersection area and the warning signal can be switched off. However, an extra safety measure must be built in to account for speed changes of cyclists and moped riders after their detection. This may be achieved with infrared or microwave detectors aimed towards the cycle path. Infrared detectors detect all heat-emiting objects, whereas microwave detectors can be set so that they only detect objects moving in one direction. When there are no longer moving objects in the area of detection, the warning light can be switched off.

3 MODEL TESTING

O.M.J. Carsten and L. Ekman

Because of the delays in completing the experimental work, a full validation of the various pedestrian submodels has had to be deferred to workpackage CM1 in DRIVE II Project V2005, VRU-TOO. The pedestrian flow and safety models have been extensively tested with data from the modelling areas in the three countries (UK, NL and S) and with fictitious data in an attempt to find bugs in the programmes. In addition, thorough checks have made on the internal consistency of the programmes. As a result a number of bugs and logic errors in the models have been revealed and corrected in the final release for DRIVE I (deliverable 13). It is expected that, as a result of the validation being carried out, further new versions will be created and released.

However, no further work on the cyclist models has been funded under DRIVE II, and it was therefore thought important to subject the bicycle models to more stringent scrutiny. It has not been possible to conduct a full-scale validation in the field because of the data collection costs involved, but it has been possible to carry out tests of the model in the "laboratory" and to verify that the outputs were both reasonable and useful. A particular attention was paid in this work to the usefulness of the model outputs for making judgments about the relative merits in safety terms of alternative signal strategies.

The method used was to analyse flows of cars and bicycles over the various stages of a signal cycle. A hypothetical junction was created with all four legs having identical flows (making the junction symmetrical reduced the number of potential outcome distributions to three, one for each direction of bicycle movement on the studied leg — right, straight and left). The hypothesized flows per leg in vehicles per hour were:

	Turning Right	Going Straight	Turning Left
Cars	150	400	50
Bicycles	60	150	30

It was also assumed that the rate of red light violation by cars or cyclists would be 0.3 per hour.

The signal cycle at the hypothesized junction was divided into twelve segments, with the green for the bicycle movements on the studied leg occurring during segments 4–9. It was necessary to create a finer split than the stages of the signal cycle, because vehicles and, in particular bicycles that have filtered to the front of a queue, will have a natural tendency to move in larger numbers at the beginning of the green stage.

For each bicycle movement (i.e. right, straight or left), there are certain car movements that can be said to be "in conflict" (in the sense that the car movements have a high *potential* to come into conflict with the bicycles). Given the stages of the signal cycle, certain conflicting car movements may be permitted simultaneously with various bicycle movements. Other car movements can be defined as going "with" the bicycles, i.e. being simultaneous but having low potential for conflict.

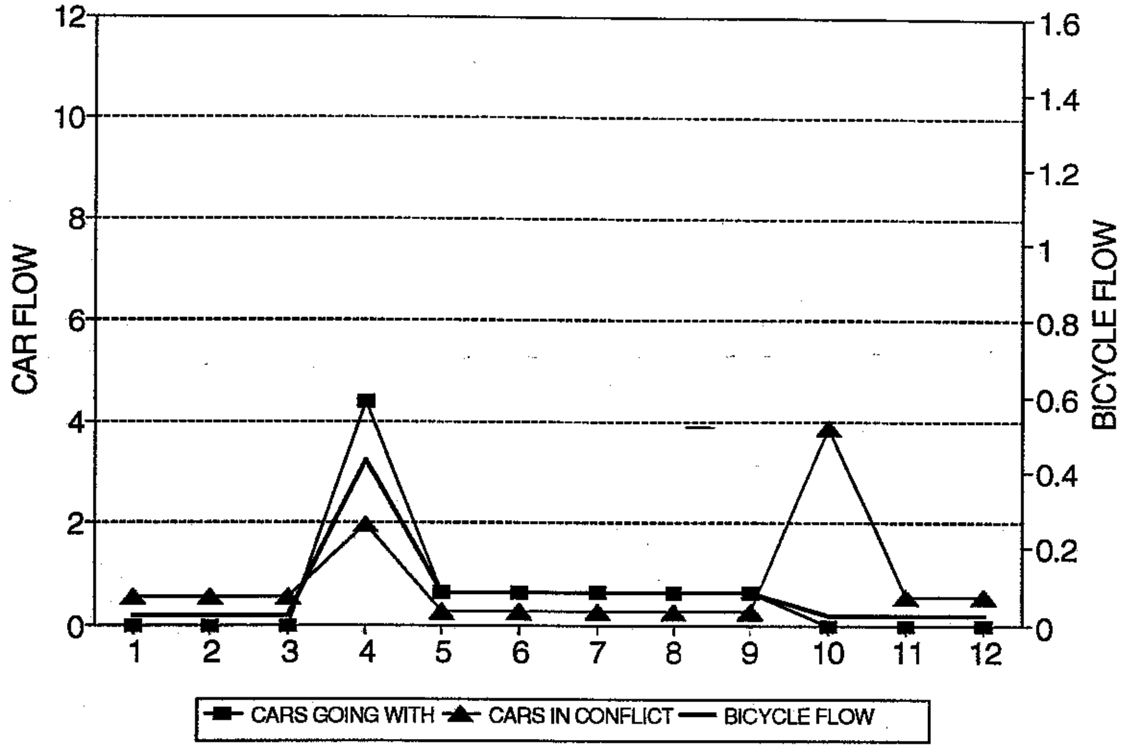


Figure 26: Flows of Right-Turning Bicycles and Relevant Cars

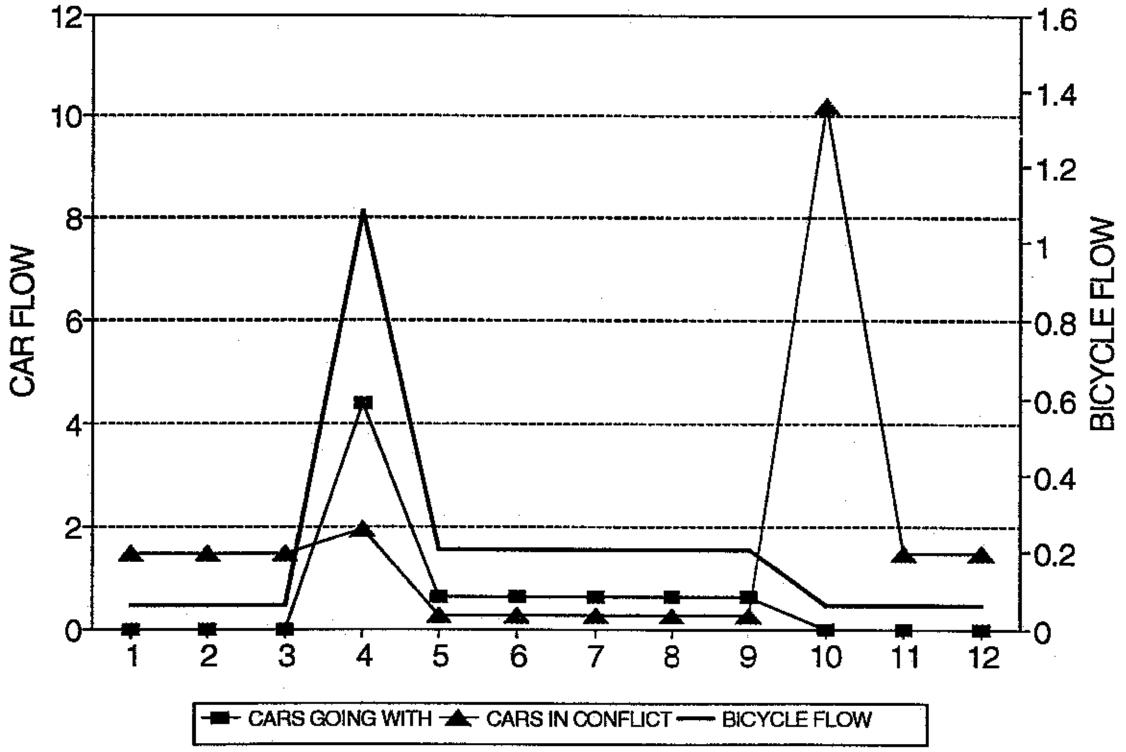


Figure 27: Flows of Bicycles Travelling Straight and Relevant Cars

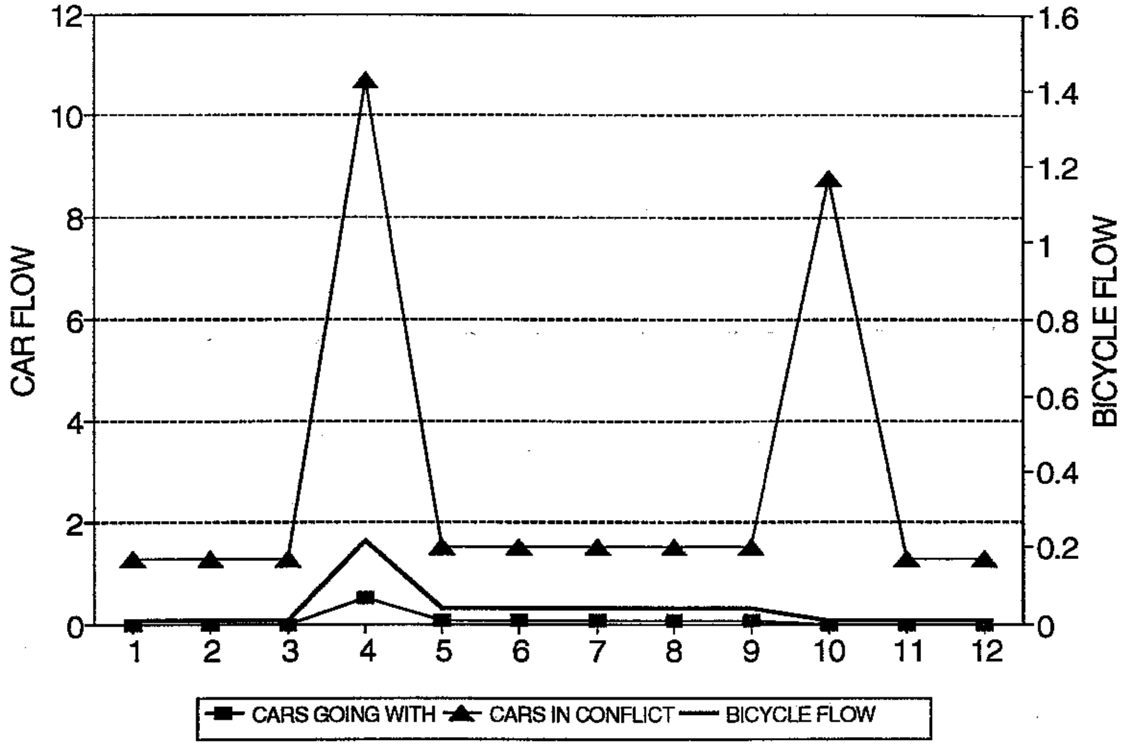


Figure 28: Flows of Left-Turning Bicycles and Relevant Cars

Figures 26–28 show the output from the simulation in graphical form. The x axis indicates the twelve segments of the signal cycle, while the two y axes show the flow of cars and bicycles. The distributions first of all indicate that the programme produces reasonable results in that the highest flow for each movement is at the beginning of the stage, with lower flows occurring subsequently. In terms of safety, they show that, as might be expected, the greatest problems are for left-turning cyclists.

The graphs also indicate the usefulness of the programme for developing alternative signal strategies. It is immediately apparent that the hypothesized strategy has a high potential for creating safety problems between cars and cyclists. Cyclists are not protected by the current signal strategy from problems with conflicting cars. Indeed, for any particular movement, cyclists would be better off (i.e. better protected from conflicting traffic) if they violated the red light rather than moving off at the beginning of the green stage.

These results show both the inherent reasonableness of the model output and the utility of the model for planning purposes. It is hoped that, in the long term, similar graphic output can be incorporated in the models themselves, so that add-on analysis packages are not required.

4 CONCLUSIONS

L. Ekman and M. Draskóczy

In an attempt to bring about parity of conditions for VRUs with other forms of road users a series of trials were carried out, within both WP4 and WP9, in which VRUs were detected as they approached a signal location. As a result of a detection the timings of the signals were amended to the advantage of the VRU.

The microwave detectors applied both in Bradford and Växjö were able to detect pedestrians in a reliable way, although the positioning of the detectors needed to be set carefully in order to avoid detecting irrelevant moving objects or pedestrians moving in a direction different from the zebra crossing. The application of pedestrian detection was different in the two experiments, but both have proved that pedestrian detection can be used to promote pedestrian mobility without adversely affecting car mobility. Both experiments have also shown an improvement in safety both by decreasing the number of car-pedestrian conflicts and, in the Växjö experiment, by decreasing pedestrian red walking.

The observation study carried out in Groningen was a preparatory step for an application of detectors for bicycles. The aim in this case would not be an alteration in the signal setting but a warning for cars that they are on a possible conflict course with a bicyclist or moped rider. The study has shown that such a function at the studied intersection is badly needed.

Microwave detection is not the only method for detecting VRUs. But is has now been shown to be a viable means for influencing signal control and for informing other road users about the presence of VRUs. Our experiments have proved that both mobility and safety can be positively influenced by those methods.

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APPENDIX

PEDESTRIAN CROSSING MANOEUVRES AT THE SIGNALIZED JUNCTION IN BRADFORD

Pedestrian Crossing Manoeuvres in Morning Peak

Crossing Point	Pre-trial					Post-trial (1)					Post trial (2)				
	Single Crossing		Double Crossing			Single Crossing		Double Crossing			Single Crossing		Double Crossing		
	Safe	Unsafe	Safe	Unsafe	Diagonal	Safe	Unsafe	Safe	Unsafe	Diagonal	Safe	Unsafe	Safe	Unsafe	Diagonal
From 1,2	36	11	4	3	1	26	12	7	5	2	30	10	9	4	-
From 9,10	20	4	2	2	–	24	3	3	1	-	17	4	4	2	–
From 13,14	8	2	–	1	–	12	-	-	-	-	9	1	–	1	–
From 15,16	15	5	–	–	–	18	5	-	-	-	20	6	–	–	1
TOTAL	79	22	6	6	1	80	20	10	6	2	76	21	13	7	1

Pedestrian Crossing Manoeuvres in Off–peak Period

Crossing Point	Pre-trial					Post-trial (1)					Post-trial (2)				
	Single Crossing		Double Crossing			Single Crossing		Double Crossing			Single Crossing		Double Crossing		
	Safe	Unsafe	Safe	Unsafe	Diagonal	Safe	Unsafe	Safe	Unsafe	Diagonal	Safe	Unsafe	Safe	Unsafe	Diagonal
From 1,2	39	13	5	19	–	40	19	7	4	1	35	16	5	2	-
From 9,10	23	6	5	6	–	27	-	6	2	-	23	2	5	2	–
From 13,14	10	8	–	–	2	8	7	-	-	-	8	7	2	–	2
From 15,16	17	6	1	–	1	20	3	-	-	1	20	5	–	1	-
TOTAL	89	33	11	25	3	95	29	13	6	2	86	30	12	5	2

Pedestrian Crossing Manoeuvres in Afternoon Peak Period

Crossing Point	Pre-trial					Post-trial (1)					Post-trial (2)				
	Single Crossing		Double crossing			Single Crossing		Double Crossing			Single Crossing		Double Crossing		
	Safe	Unsafe	Safe	Unsafe	Diagonal	Safe	Unsafe	Safe	Unsafe	Diagonal	Safe	Unsafe	Safe	Unsafe	Diagonal
From 1,2	28	7	1	2	–	28	12	3	2	-	35	9	4	1	-
From 9,10	16	3		7		16	2	4	1	2	19	3	3	-	1
From 13,14	61	7	–	–	–	45	23	3	2	-	67	15	2	-	–
From 15,16	20	6	–	–	–	21	3	3	-	1	24	7	1	1	-
TOTAL	125	23	1	9	–	110	40	13	5	3	145	34	10	2	1

Pedestrian Crossing Manoeuvres in Evening Peak Period

Crossing Point	Pre-trial					Post-trial (1)					Post-trial (2)				
	Single Crossing		Double crossing			Single crossing		Double Crossing			Single Crossing		Double Crossing		
	Safe	Unsafe	Safe	Unsafe	Diagonal	Safe	Unsafe	Safe	Unsafe	Diagonal	Safe	Unsafe	Safe	Unsafe	Diagonal
From 1,2	20	10	11	8	–	20	7	8	4	-	18	8	12	4	-
From 9,10	21	4	3	1	2	18	2	5	-	-	22	2	3	–	1
From 13,14	5	3	–	1	–	12	7	-	1	-	13	6	-	-	-
From 15,16	21	2	–	1	–	18	1	-	-	-	20	1	–	–	–
TOTAL	67	19	14	11	2	68	17	13	5	-	73	7	15	4	1