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VRU-TOO

Vulnerable Road User Traffic Observation and Optimization

DRIVE II Project V2005
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Micro-Level Behavioural and Conflict Changes in the VRU-TOO Pilot Projects

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EXECUTIVE SUMMARY

This report describes the results of an evaluation of pilot project pedestrian detection systems installed in three different European cities at in total six different sites. The implemented systems had the improvement of safety and comfort of pedestrians as objectives. The systems provided early detection of pedestrians approaching the crossing facility and detection of the presence of pedestrian on the crossing facility, allowing the onset of a pedestrian green phase or an extension of such a green phase.

The evaluation involved the registration of pedestrian behaviour and pedestrian-vehicle encounters and conflicts. Pedestrian behaviour was recorded on videotape, conflicts were scored on the spot by trained observers. The behaviour recorded on videotape was later analysed using approach speed, normative behaviour and appropriate use of the crossing facilities as main indicators. In addition, pedestrian signal settings were recorded for each crossing. The evaluation design used a before/after measurement design with the after measurements being taken at least two weeks after the system implementation.

The results indicated that although red light violations were reduced at some sites, they remained at a high level. The implementations had some positive effects on the normative behaviour of pedestrians. The percentage of pedestrians getting involved in encounters with motorized traffic was reduced at one site, increased at another and remained unchanged at the other sites. A significant reduction in conflicts was observed at several sites, but at other sites conflict occurrence remained unchanged.

The system implementations had a very distinct positive effect on pedestrian delay. Required waiting times were reduced at all but one site and at some sites the reductions were substantial. Pedestrian comfort was also improved by an increase in the percentage of pedestrians arriving during the pedestrian green phase and the percentage being able to complete their crossing during pedestrian green.

In summary, the evaluation study demonstrated that some safety effects and substantial effect on comfort were achieved by the implementation of the systems. The effects can be further optimized by selecting sites that fulfil specific requirements for successful implementation. Red light violation by pedestrian remains a serious safety problem and further studies should be undertaken how further reductions can be achieved by optimizing signal settings.

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1 OBJECTIVES

The objectives of this workpackage are to assess the effects of the pilot projects implementations in terms of safety and comfort. In operational terms, the effects are measured in terms of the micro-level behavioural changes and changes in occurrence of conflicts between pedestrians and vehicular traffic.

The formulated hypotheses regarding the micro-level behaviour changes were:

Hypothesis 1:	*The number of pedestrians that arrive during the red light stage and violate the red light will decrease.*
Hypothesis 2.1:	*The time a pedestrian who arrives in the red light phase will have to wait for green light will decrease.*
Hypothesis 2.2:	*The time a pedestrian who arrives in the red light phase actually waits before starting to cross will decrease.*
Hypothesis 3:	*The number of pedestrians having a pedestrian/vehicle encounter will decrease.*
Hypothesis 4:	*The pedestrians will not behave in a less normative manner.*
Hypothesis 5:	*The number of pedestrians crossing in comfort will increase.*

The general hypothesis for the conflict studies was that the number of conflicts observed would reduce between the before and after situations as a direct effect of the pilot project implementations. In addition, a number of operational hypotheses were formulated as this would allow a detailed analysis of the effects of the implementations on conflict occurrence. These hypotheses were formulated as follows:

- The number of pedestrian/vehicle conflicts will decrease
- The number of pedestrian/vehicle conflicts per lane will decrease
- The number of pedestrian/vehicle conflicts for each pedestrian direction will decrease
- The number of pedestrian/vehicle conflicts according to whether the pedestrian is in the first, second or last lane will decrease
- The ratio of conflicts of pedestrians crossing to conflict will reduce

These hypotheses were tested for each site separately.

2 METHODS EMPLOYED

2.1 DESCRIPTION OF SITES AND INTERVENTIONS

Elefsina

The experimental site in Elefsina was located in the centre of the town on a road lined with shops. The two-way road is on the main route from Athens to Corinth, even though a new by-pass has been built. The side road is on the pedestrian route from the station to the industrial zone. At the intersection, there is a newly installed traffic signal system with push-buttons for pedestrians. The detection system that was installed allowed early detection of pedestrians approaching on the main pedestrian route and allowed detection of pedestrians on the crossing. Detection of approaching pedestrians triggers the onset of a pedestrian green phase, whereas detection of pedestrians on the crossing increases the length of the pedestrian green phase.

Porto

The experimental site in Porto was located on a main arterial west of the city centre. The road is a dual carriageway with a central refuge with tramlines in both directions. For practical reasons, the experimental site was considered as two sites divided by the tramlines: a pedestrian crossing near a school (site 1) which vehicular traffic would encounter after the intersection and a crossing which the traffic would encounter before the intersection (site 2). Microwave detection devices were installed on the newly altered signal poles to detect pedestrians approaching the crossing point. Detection of approaching pedestrians triggers the onset of a pedestrian green phase or extends the green phase if that is already in operation.

Leeds

In Leeds three experimental sites were studied. These sites were located at signalised crossings on the one-way city-centre loop in a stretch of road where there is a large shopping centre on each side of the road. The sites were separated by a couple of hundred metres. The first site is a pedestrian crossing facility across two wide lanes. Site 2 is another pedestrian crossing facility, which is located directly between two shopping centres and has, as a consequence, extremely high pedestrian flows. The third site is a pedestrian crossing facility across a three lane section of the city centre loop. All pedestrian crossing facilities are signalled under a series of fixed time plans with various cycle times normally operated with push buttons for pedestrians. The microwave detection devised that were installed on these sites allowed early detection of approaching pedestrians which would trigger the onset of a pedestrian green phase or extend the green phase if already in operation.

A full description of the pilot project implementations is presented in Deliverable V2005/10 (Demonstrator for Greek site); Deliverable V2005/9 (Demonstrator for Portuguese site) and Deliverable V2005/13 (Demonstrator for English site). For an overview see the Appendix.

2.2 VIDEO OBSERVATION STUDY

Video recordings were made at each site both before and after the implementation of pilot project detection schemes. For this purpose, a video camera was mounted to a pole near the crossing place, or where appropriate, situated in a nearby building. In addition light-sensitive devices were attached to the traffic lights and the pedestrian lights and connected to a transmitter. A receiver was attached to the video recorder allowing the registration of the signal settings on videotape.

At all sites, five hours of recording were made during five working days both before and at least two weeks after the detection devices were installed. The recording hours were chosen such that both peak and off-peak periods of vehicle and pedestrian flows were included. Recording only took place during dry weather periods.

In both the before and after measurement a selection of 100 pedestrian crossing movements were analysed for the crossing in Elefsina and each of the two sites in Porto, and 250 pedestrians at each site in Leeds. Every n^{th} pedestrian was selected, where 'n' was a fixed number which could differ between sites depending on the pedestrian flow and the video material available. Pedestrians who crossed the road partly or completely outside the area of the pedestrian facility or 5 metres to either side of the facility were not included in the analysis. In addition, pedestrians were also excluded if their crossing behaviour could not be observed completely because, for example, a bus was blocking the view. The pedestrians were not aware that they were participating in an experiment and that their behaviour was being observed.

For each crossing, a number of behavioural variables were scored. These variables included:

- approach speed at the kerb
- speed change before crossing
- head movements before crossing and during crossing
- course and speed during crossing

In addition, the pedestrian signal setting at the arrival, start of crossing and completion of crossing were recorded. The occurrence of pedestrian/vehicle encounters was also recorded. Data analysis techniques followed the format and procedures in accord with the input and output data standards formulated earlier in the project (see Westra and Rothengatter, Deliverable V2005/3).

2.3 CONFLICT OBSERVATIONS

Conflicts between pedestrians and motorised traffic are scored in accord with the Swedish Traffic Conflicts Technique developed by the University of Lund (Hydén, 1987). The Traffic Conflicts Technique is a complementary technique to accident analysis for safety assessment. The basic concept is that there is a relationship between serious conflicts and injury accidents. These accident comparable events called serious conflicts, are recorded by human observers. A serious conflict is a conflict with a small margin. The margin is set by the TA-value (time to accident-value) and the initial speed. The TA-value is the time from the moment when one road user starts an avoidance action to the moment a collision would have occurred if no evasive action had been undertaken. The border line which distinguishes serious conflicts from non-serious conflicts represents the time margin necessary for braking plus 0.5 seconds. The observations were carried out by a trained observer at the spot. In Elefsina 45 hours of observation were carried out before the implementation and 45 hours after the implementation. In Porto 15 days of observation were carried out equally divided over the before and after period. In Leeds each of the sites was observed for 25 hours before and 25 hours after the implementation.

3 HYPOTHESES

Prior to data analysis the intended effects of the pilot project implementations on the pedestrian behaviour and conflicts were operationalised in terms of operational hypotheses on the basis of the stated overall aim of improving comfort and safety. The hypotheses were generally tested for all observed pedestrians crossing the road. The exception to this was the Porto location, which was adjacent to a school. At the Porto location, about twice as many children were observed as at the sites in Elefsina and Leeds. For Porto, the hypotheses concerning red light violation, delay, encounters, and normative behaviour were also tested separately for children only (defined as unaccompanied, 6–17 years old).

The formulated hypotheses regarding the micro-level behaviour changes were:

Red light violation

Hypothesis 1: *The number of pedestrians that arrive during the red light stage and violate the red light will decrease.*

This was separately tested for the following two types of red light violation:

- conflict-free violation: crossing when the pedestrian light is red and the vehicle traffic light is also red (this includes "early" and "late" walkers);
- conflictuous violation: when the pedestrian light is red and the vehicle traffic light is green or yellow.

Delay

Hypothesis 2.1: *The time a pedestrian who arrives in the red light phase will have to wait for green light will decrease.*

Hypothesis 2.2: *The time a pedestrian who arrives in the red light phase actually waits before starting to cross will decrease.*

In addition to hypothesis 2.2, it was tested whether there was a change in the number of pedestrians arriving in the red light phase and waiting longer than 10 seconds; 20 seconds or 30 seconds.

Encounters

Hypothesis 3: *The number of pedestrians having a pedestrian/vehicle encounter will decrease.*

An encounter was defined as "a situation in which the pedestrian and/or the vehicle adapts his or her behaviour by changing speed and/or course (stopping for red light not included) to avoid a conflict".

Normative behaviour

Hypothesis 4: *The pedestrians will not behave in a less normative manner.*

Normative behaviour was defined in accord with earlier description of the behavioural elements required for a safe crossing. Thus, a number of operational hypotheses could be formulated to test the hypothesis formulated above.

H4.1: The number of people arriving during the red light phase and stopping at the kerb will not decrease.
H4.2: The number of people making head movements in the relevant directions before crossing each separate lane will not decrease.
H4.3: The number of people approaching the kerb at a normal or slow pace will not decrease.
H4.4: The number of people crossing the road in a straight line will not decrease.
H4.5: The number of people using the pedestrian facility as intended will not decrease.

Comfort
Hypothesis 5: *The number of pedestrians crossing in comfort will increase.*
This hypothesis was tested by considering the following hypotheses:

H5.1: The percentage of pedestrians arriving during the green light phase will increase.
H5.2: The number of pedestrians that depart from the kerb and arrive at the other side during the green light phase will increase.

To test the hypotheses, a chi-square test for nominal variables and t-tests for ratio variables was used. The level of significance was set at .05, but p-values below .15 were also considered as relevant.

The general hypothesis for the conflict studies was that the number of conflicts observed would reduce between the before and after situations as a direct effect of the pilot project implementations. In addition, a number of operational hypotheses were formulated as this would allow a detailed analysis of the effects of the implementations on conflict occurrence. These hypotheses were formulated as follows:

- The number of pedestrian/vehicle conflicts will decrease
- The number of pedestrian/vehicle conflicts per lane will decrease
- The number of pedestrian/vehicle conflicts for each pedestrian direction will decrease
- The number of pedestrian/vehicle conflicts according to whether the pedestrian is in the first, second or last lane will decrease
- The ratio of conflicts of pedestrians crossing to conflict will reduce

These hypotheses were tested for each site separately.

4 RESULTS

4.1 THE ELEFSINA STUDY

Red light violation

The red light violations remained unchanged (from 53% to 52%). For further analysis a division was made between conflictuous and non-conflictuous violations. Non-conflictuous violations were defined as those that took place while the vehicle traffic signal was red, conflictuous as those that took place while vehicle traffic lights showed green. The conflict-free violations decreased from 15% to 11%; the conflictuous violations increased from 39% to 42% but neither change was significant.

Delay

The expected time a pedestrian has to wait at the kerb when arriving in the red light phase decreased by 5 seconds from 35 secs to 30 secs ($p<.15$). The actual time the pedestrians waited decreased only with one second, which is not a significant change. However, when considering the distribution of realised waiting times, it appears that long waiting times are reduced (see Table 1).

Table 1: Realised waiting time at the kerb for pedestrians arriving during the red light phase in Elefsina

	Before	After	Sign.
Waiting > 10 seconds	52.3%	63.1%	-
Waiting > 20 seconds	37.5%	41.7%	-
Waiting > 30 seconds	28.4%	17.9%	*

*=p<.15

Encounters

The percentage of pedestrians becoming engaged in a pedestrian/vehicle encounters decreased from 38% to 23% ($p<.05$). This was true for both first-lane encounters (from 14% to 4% ($p<.05$)) and second-lane encounters (from 24% to 19% ($p<.10$)). The decrease mainly concerned encounters in which the pedestrian crossed behind the vehicle.

Normative behaviour

Normative behaviour remained on the whole unchanged. A small increase in pedestrians showing normative looking behaviour was found ($p<.15$). The percentage pedestrian stopping at a pedestrian red light increased, but this increase was not significant.

Table 2: Normative behaviour in Elefsina

	Before	After	Sign.
Stopping at red	75.0%	83.3%	–
Head movements	55.0%	66.0%	*
Normal approach pace	100.0%	100.0%	–
Crossing straight	47.0%	46.0%	–
Using crossing facility	22.0%	22.0%	–

*=p<.15

Comfort
Table 3 shows that there is a non-significant increase in both the number of pedestrians that arrive in the green light phase and the number that complete the crossing during the green stage.

Table 3: Comfort in Elefsina

	Before	After	Sign.
Arriving during green	12.0%	16.0%	–
Completing crossing during green	5.0%	9.0%	–

Conflicts
In Elefsina the conflict studies were conducted at two pedestrian crossings situated on the two main arms of the experimental site. The analysis has divided the site into four locations (see Appendix A). The first test was to ascertain whether the overall observed number of conflicts had significantly changed after the pilot project implementation. Overall, 82 conflicts were observed before and 64 after implementation, which is a significant reduction (z =2.04, critical value 1.96, p=0.25 one-tailed).

Analysis of the number of conflicts by location revealed that, at location 1, 25 conflicts were observed before and 17 after the implementation, which is a significant reduction (z=1.7, critical value 1.645, p=0.5 one-tailed). No change in the number of conflicts observed was found at location 2. At location 3, a non-significant increase was found in the number of conflicts observed from 24 to 28 after implementation. At location 4 the number of observed conflicts significantly decreased from 18 to 4 after implementation (z=3.42, critical value 3.291, p=0.0005 one-tailed).

Analysis of the number of conflicts per crossing stage was performed for each of the locations separately. At location 1, the number of conflicts occurring when the pedestrian was in the first half of the crossing increased non-significantly from 4 to 6 after implementation. At the same location, 21 conflicts were observed involving pedestrians during the second half of their crossing before and 11 after the implementation which is a significant reduction (z=2.29, critical value 1.96, p=0.025 one-tailed). At location 4 the number of conflicts occurring when the pedestrian was in the first half of the crossing was reduced from 6 to 3 after implementation, which is significant at the level of p=0.09. The number of conflicts occurring when the pedestrian was in the second half of the crossing was reduced from 12 to 1, which is significant at the level of p=0.0004. At location 2 the number of conflicts remained constant for both first half and second half crossings. At location 3, a non-significant increase in observed conflicts was found for first half crossings (from 11 to 12) and for second half crossings (from 13 to 16).

In addition, data was collected on the light phase at the time of the conflict. In the before study 9.8% of conflicts were recorded without the light phase being known and in the after study this figure was 18.8%. The total number of conflicts in the before study which occurred during pedestrian green phase was 41 (50%) and in the after study this was 29 (45%).

4.2 THE PORTO STUDY

Red light violation

In the Porto study, the two parts of the crossing are considered as two separate sites. Site 1 is the crossing near the school, site 2 is the crossing on the other carriageway. Red light violations increased from 84% to 93% at site 1, which is a non-significant change. Red light violation decreased at site 2 from 83% to 67% (which is significant at p<.10). The red light violations of the observed children increased at site 1 from 91 to 97%, and decreased at site 2 from 90% to 69%. Further analysis involved separate consideration of conflictuous and conflict-free violations. This revealed that the increase in red light violations at site one mainly concerned conflictuous violations. At site 2, the decrease in violations committed by children involve mainly conflictuous violations (see Table 4).

Table 4: Non-conflictuous and conflictuous red light violations in Porto

		SITE 1			SITE 2		
		Before	After	Sign.	Before	After	Sign.
Non-conflictuous violations	All	12.4%	6.6%	–	14.3%	3.7%	**
	Children	8.8%	6.7%	–	5.3%	6.3%	–
Conflictuous violations	All	71.9%	86.8%	*	69.0%	63.0%	–
	Children	82.4%	90.0%	–	84.2%	62.5%	*

*=p<.15; **=p<.10

Delay

The expected time a pedestrian has to wait at the kerb when arriving in the red light phase did not change at site 1, whereas at site 2 the expected waiting time decreased with more than 14 seconds from 37 secs to 29 secs (p<.05). The actual time the pedestrians waited at site 1 decreased from 41 secs to 36 secs (p<.15). At site 2, on the contrary, the realised delay increased with almost 7 seconds to 13 secs (p<.05). This increase was also found for children (9.5 seconds, p<.05). Table 5 illustrates that at site 2 the increase in waiting time occurs amongst the children in particular.

Table 5: Realised waiting time at the kerb for pedestrians arriving in the red light phase in Porto

		SITE 1			SITE 2		
		Before	After	Sign.	Before	After	Sign.
Waiting >10 seconds	All	33.7%	22.4%	*	31.0%	37.0%	–
	Children	26.5%	26.7%	–	15.8%	43.8%	**
Waiting > 20 seconds	All	15.7%	10.5%	–	16.7%	22.2%	–
	Children	8.8%	6.7%	–	0.0%	18.8%	***
Waiting > 30 seconds	All	12.4%	6.6%	–	7.1%	16.7%	–
	Children	5.9%	3.3%	–	0.0%	12.5%	*

*=p<.15; **=p<.10; ***=p<.05

Encounters

At site 1 a significant increase in the number of pedestrian/vehicle encounters from 30% to 42% was found (p<.10), which also seemed to be the case for children (increase from 40% to 50%; not significant). At site 2 a decrease in pedestrian/vehicle encounters involving children was found (from 21% to 9%; p<.15).

Table 6: Encounters in Porto

		SITE 1			SITE 2		
		Before	After	Sign.	Before	After	Sign.
First lane encounters	All	14.0%	22.0%	*	6.0%	7.0%	–
	Children	23.7%	28.9%	–	10.4%	5.7%	–
Second lane encounters	All	20.0%	24.0%	–	10.0%	2.0%	***
	Children	23.7%	26.3%	–	18.8%	2.9%	***
Pedestrian crossing in front of vehicle	All	24.0%	28.0%	–	7.0%	7.0%	–
	Children	28.9%	36.8%	–	12.5%	5.7%	–
Pedestrian crossing behind vehicle	All	8.0%	16.0%	**	6.0%	2.0%	*
	Children	13.2%	15.8%	–	10.4%	2.9%	–

*=p<.15; **=p<.10; ***=p<.05

At site 1, the increase in encounters concerns mainly encounters taking place in the first half of the crossing. The type of encounter that shows a significant increase is that where the pedestrian waits until the vehicle has passed and then crosses behind the vehicle. At site 2, the decrease in encounters is significant for the encounters taking place during the second half of the crossing. The reductions concern both pedestrian crossing in front and behind approaching vehicles, although only the latter change reaches significance (see Table 6).

Normative behaviour

Several changes in the normative behaviour of the pedestrians were found. Table 7 presents an overview. At site 1, both adults and children made more head movements before crossing (p<.05) and the pedestrian were more likely to approach the kerb at a normal pace, although this latter change is not significant. However, crossing in a straight line and making proper use of the crossing facility decreased significantly.

At site 2, all changes were in the positive direction, that is to say towards more normative behaviour. Of these changes, only the increase in normal approach and the crossing in straight line of children reached significance (p<.15).

Table 7: Normative behaviour in Porto

		SITE 1			SITE 2		
		Before	After	Sign.	Before	After	Sign.
Stopping at red	All	67.4%	57.9%	–	69.0%	64.8%	–
	Children	58.8%	56.7%	–	57.9%	56.3%	–
Head movements	All	63.0%	78.0%	***	50.0%	57.0%	–
	Children	52.6%	81.6%	***	47.9%	57.1%	–
Normal approach pace	All	89.0%	91.0%	–	82.0%	90.0%	*
	Children	81.6%	92.1%	–	77.1%	85.7%	–
Crossing in straight line	All	74.0%	60.0%	***	78.0%	82.0%	–
	Children	76.3	63.2%	–	68.8%	82.9%	*
Using crossing facility	All	70.0%	50.0%	***	79.0%	84.0%	–
	Children	81.6%	55.3%	***	72.9%	85.7%	–

*=p<.15; **=p<.10; ***=p<.05

Comfort
The percentage of pedestrians arriving during the green phase of the pedestrian light increases from 9% to 18% at site 1 (p<.10) and from 22% to 45% at site 2 (p<.05).

Table 8 shows that at site 1 a significant increase is found in the percentage of pedestrians completing the crossing during the green phase. At site 2, this percentage decreases, although this decrease is not significant.

Table 8: Completing crossing during green phase in Porto

	SITE 1			SITE 2		
	Before	After	Sign.	Before	After	Sign.
All	3.0%	10.0%	***	61.0%	54.0%	–

*=p<.15; **=p<.10; ***=p<.05

Conflicts

A total of 133 pedestrian/vehicle conflicts were observed before implementation against a 130 conflicts after the implementation. This change is not significant (z= .632, critical value 1.645). Table 9 presents the number of conflicts per site showing that there was a 6.3% reduction in the number of conflicts at site 1 and a 3.7% increase in conflicts at site 2. Neither of these changes was significant. At site 1 z= .391 and at site 2 z= .576; in both cases the critical value was 1.645.

Table 9: Number of conflicts per site in Porto before and after implementation

	SITE 1			SITE 2		
	Before	After	% Change	Before	After	% Change
Pedestrian to vehicle conflicts	79	74	–6.3	54	56	+3.7

In a further analysis, conflict occurrence was analysed separately for direction of travel (towards or away the central tramline refuge) and for each lane of crossing (see Appendix A). Analysis of the number of conflicts per lane revealed that at site 1 the observed conflicts at lane 1 decreased from 28 to 11 after implementation, which is a significant reduction (z=3.31, critical value 3.291, p=0.0005 one-tailed). At lane 2 an increase from 51 to 63 observed conflicts was found after implementation, which is significant at the level of p=0.10. At site 2 a non-significant reduction of conflicts occurring at lane 1 was found (from 32 to 27), whereas on lane 2 the number of conflicts increased from 22 to 27 after implementation, which increase is non-significant.

Analysis of the number of conflicts per direction of crossing was considered particularly important at these sites as the implementations respond differently according to the pedestrian's approach direction. The first tests relate to the overall directions by pedestrians either towards the central tramline refuge or away from it. In the before study the number of conflicts involving pedestrians crossing towards the refuge was 76 and after implementation this had increased to 90. This increase is significant at the level of p=0.10. There were 57 conflicts involving pedestrians crossing from the refuge in the before study and 40 after implementation. This reduction is significant (z=2.32, critical value 1.96, p=0.025 one-tailed).

Further analysis considered the number of conflicts related to the pedestrian volumes. For this purpose, pedestrian volumes were collected over a period of five hours and since the conflicts had been collected over 75 hours, conflict ratios were calculated by dividing the volumes by the number of conflicts divided by 15. At site 1, the ratio before implementation was 66:1 and after implementation 54:1. Likewise, at site 2 the ratio before implementation was 138:1 and after implementation 120:1. This indicates that the percentage of pedestrians getting involved in a conflict increased at both sites after implementation.

Vehicle counts revealed that there had not been significant changes in vehicle volumes before and after the implementation.

4.3 THE LEEDS STUDY

In Leeds, implementations were carried out at three sites, situated along the north side of the one-way loop road around the city centre. The traffic flows from west to east along the stretch of road, and the sites are numbered in the direction of traffic flow. Sites 1 and 3 were at locations with comparatively low pedestrian flows, but site 2 was located between two large indoor shopping centres, with consequently very high flows of pedestrians.

Red light violations

At two of the sites studied, no changes in red light violations were observed (site 1: from 86 to 87%; site 3: from 85 to 87%). At site 2 a significant reduction of red light violations from 97% to 88% was found. Considering conflictuous and non-conflictuous violations separately reveals that conflictuous violations were reduced at all sites and significantly so at site 1 and 2 (see Table 10.

Table 10: Conflictuous and non-conflictuous red light violations in Leeds

		Before	After	Sign.
Site 1	Non-conflictuous	5.6%	14.6%	***
	Conflictuous	80.6%	72.4%	***
Site 2	Non-conflictuous	26.7%	29.5%	-
	Conflictuous	70.0%	58.2%	***
Site 3	Non-conflictuous	6.8%	14.7%	***
	Conflictuous	78.3%	72.3%	-

*=p<.15; **=p<.10; ***=p<.05

Delay

At all three sites there was a significant decrease in the required time a pedestrian had to wait for green pedestrian light (all p<.05). The decreases appeared to be very large, which among other things was due to a number of extreme values in the before measurements when a pedestrian violated the red light and did not push the button: in those cases it could take a long time before the green pedestrian light will show. These extreme values were missing in the after measurements because there was always a call for a green pedestrian light phase if a pedestrian crossed the road, since the detecting system would trigger such a phase regardless of the pedestrian making use of the push-button system. To rule out the effect of these extreme values, the median as well as the mean required waiting time has been analysed. This does not, however, change the results dramatically.

Table 11: Required waiting times in Leeds

secs	SITE 1 Before	SITE 1 After	SITE 2 Before	SITE 2 After	SITE 3 Before	SITE 3 After
mean	40	24	21	17	55	22
median	34	23	21	16	34	20

The mean realised waiting time hardly changed between before and after implementation and varied between 9 and 11 seconds at all sites. However, longer waiting times appeared to be considerably reduced at site 3 and to a lesser extent at the other sites (see Table 12).

Table 12: Realised waiting time at the kerb for pedestrians arriving during the red light phase in Leeds

		Before	After	Sign.
Site 1	Waiting > 10 seconds	33.3%	41.2%	**
	Waiting > 20 seconds	17.6%	21.1%	–
	Waiting > 30 seconds	10.2%	8.0%	–
Site 2	Waiting > 10 seconds	48.0%	34.9%	***
	Waiting > 20 seconds	20.7%	12.3%	**
	Waiting > 30 seconds	6.0%	4.1%	–
Site 3	Waiting > 10 seconds	33.9%	38.2%	–
	Waiting > 20 seconds	21.7%	14.7%	**
	Waiting > 30 seconds	7.7%	3.1%	***

*=p<.15; **=p<.10; ***=p<.05

Encounters

At site 1 there was a significant increase in the percentage of pedestrians having an encounter with a vehicle (from 6 to 12%; p<.05), whereas there was a non-significant decrease at the other two sites (from 5 to 3% and from 11 to 9%, respectively). The increase at site 1 concerns second lane encounters, and mainly pedestrians crossing in front of approaching vehicles.

Table 13: Encounters in Leeds

		Before	After	Sign.
Site 1	First lane	3.6%	3.6%	–
	Second lane	3.2%	8.0%	***
	Pedestrians crossing in front	4.0%	9.6%	***
	Pedestrians crossing behind car	2.8%	2.0%	–
Site 2	First lane	2.4%	0.4%	**
	Second lane	2.0%	1.6%	–
	Third lane	2.8%	2.0%	–
	Pedestrians crossing in front	3.2%	1.6%	–
	Pedestrians crossing behind car	2.0%	1.2%	–
Site 3	First lane	0.4%	1.6%	–
	Second lane	8.0%	5.2%	–
	Third lane	2.8%	5.2%	–
	Pedestrians crossing in front	9.2%	8.0%	–
	Pedestrians crossing behind car	1.6%	0.8%	–

*=p<.15; **=p<.10; ***=p<.05

Normative behaviour

Table 14 shows that at site 1 and site 3 there was no decrease in normative behaviour and that in fact both crossing in straight and use of crossing facility improved significantly at site 1 and stopping at red improved significant at site 3. At site 2 significantly less people were making head movements in the direction of approaching vehicles before crossing each lane.

Table 14: Normative behaviour in Leeds

		Before	After	Sign.
Site 1	Stopping at red	57.9%	61.8%	–
	Head movements	68.4%	67.6%	–
	Normal approach pace	97.2%	98.8%	–
	Crossing straight / normal pace	25.2%	36.0%	***
	Using 'zebra'	36.0%	50.0%	***
Site 2	Stopping at red	67.3%	65.1%	–
	Head movements	23.2%	11.6%	***
	Normal approach pace	97.2%	97.6%	–
	Crossing straight / normal pace	62.0%	60.4%	–
	Using 'zebra'	99.6%	99.6%	–
Site 3	Stopping at red	58.4%	67.0%	**
	Head movements	31.6%	29.6%	–
	Normal approach pace	97.6%	97.2%	–
	Crossing straight / normal pace	56.0%	52.0%	–
	Using 'zebra'	61.2%	59.6%	–

*=p<.15; **=p<.10; ***=p<.05

Comfort

The percentage of pedestrians arriving during the green light phase was increased at site 1 and site 3 (from 9 to 17% and 11 to 22%, respectively, both p<.05). At site 2 there was no change. The percentage of pedestrians completing their crossing during the green light phase increased at sites 1 and 2, whereas no change was found at site 3 (see Table 15).

Table 15: Pedestrians completing crossing during green phase in Leeds

	Before	After	Sign.
Site 1	0.4%	4.8%	***
Site 2	26.8%	37.2%	***
Site 3	3.6%	3.2%	–

*=p<.15; **=p<.10; ***=p<.05

Conflicts

The number of conflicts observed at the Leeds sites was relatively small. At site 1, 4 conflicts were observed before the implementation and 1 afterwards. This change is significant at the .10 level but not at the .05 level (p=.09, one-tailed). At site 2, 41 conflicts were observed before and 34 after the implementation. This reduction is not significant (p=.14, one-tailed). At site 3, ten conflicts were observed before and after implementation (see Table 16). If the three sites in Leeds are combined, the total number of conflicts observed was 55 before implementation and 45 after implementation. This change is significant at the .10 level, but not at the .05 level (p=.08, one-tailed).

Table 16: Conflicts observed before and after implementation in Leeds

	Before	After	% Change
Site 1	4	1	–75%
Site 2	41	34	–17%
Site 3	10	10	0%

No further analysis was undertaken on the conflicts at sites 1 and 3, because of the low numbers of conflicts involved. Even though the reduction in number of conflicts observed at site 2 is non-significant, conflict occurrence was also analysed per crossing lane and per crossing direction. The lay-out of this site, which is a very busy city centre crossing between two shopping centres, is presented in Appendix A.

Analysis of the number of conflicts occurring per lane revealed that on lane 1 a non-significant reduction from 8 to 6 conflicts occurred after implementation. On lane 2, the number of conflicts increased from 8 to 11, which also is non-significant. On lane 3, a reduction in the number of conflicts was found from 29 to 19 after implementation which is a significant reduction (p=0.05, one-tailed).

Although the implementation involved the installation of pedestrian detectors at both approaches to the crossing, the number of conflicts per direction of crossing was also analysed. In neither direction was the reduction in conflicts significant, however.

Analysis of the number of conflicts depending on the crossing stage (in this case, the first, second or third lane of crossing) was performed for each crossing direction. Lanes 1 and 2 were not considered in detail as the numbers were too low to allow meaningful analysis. On lane 3 almost all conflicts appeared to involve pedestrians who were in the last stage of their crossing. The number of third-lane conflicts observed was 23 before and 14 after implementation, which is significant ($p=0.025$, one-tailed).

In addition to the analyses above, it was possible to analyse conflicts in relation to the light phase and in particular whether the pedestrian was violating the pedestrian red light. This appeared to be the case in 95% of the conflicts (of which the light phase was recorded) before implementation and for all conflicts after implementation.

Finally, conflict occurrence was related to pedestrian and vehicle volumes. Pedestrian counts were used as a basis for calculation conflict ratio's per direction of travel. The ratio of pedestrians crossing northbound (from lane 3 to lane 1) increased from 2652:1 to 3144:1. For the opposite direction these ratios were 1415:1 and 1455:1. Vehicle counts made over a period of 5 hours were used to calculate vehicle to conflict ratios resulting in a ratio of 628:1 before and 725:1 after implementation.

5 CONCLUSIONS

The main objectives of the implementations was to improve pedestrian safety and comfort. For the purpose of the evaluation of the implementation pedestrian behaviour and conflicts were observed in relation to vehicle traffic and for each a number of specific hypotheses were formulated, which will form the basis for the conclusions formulated below.

- The percentage of pedestrians who violated the red pedestrian light was reduced at two sites but increased at another. Except for the site in Elefsina, very high values (> 80%) were found both before and after the implementation. It must be concluded that the implementation did not influence pedestrians' inclination to habitually violate red pedestrian lights.
- The majority of the violations occurred while vehicle traffic lights were green. This is true both before and after the implementation, although the implementation tended to influence the conflictuous violations more than the non-conflictuous ones.
- On the whole, the implementation had a slightly positive effect on pedestrians' normative behaviour. Stopping at red improved or remained unchanged at all but one site. The same applies for head movements. A normal approach speed was improved or remained unchanged at all sites. Usage of facilities and straight crossing remained unchanged or improved at all but one site. There are remarkable disparities between the percentages pedestrians at the different sites observed to display normative behaviour. The percentage of pedestrians making appropriate head movements, for example, varied from 11% in Leeds to 78% in Porto. Normal approach speed was included in the study because of its relation to conflict involvement. It is therefore encouraging to note that after implementation more than 90% of the pedestrians approach the crossing facilities at normal pace.
- The percentage of pedestrians getting involved in an encounter with a vehicle was reduced at one site (Elefsina), increased at another (Porto site 1) and remained largely unchanged at the others. At the Elefsina site, the number of conflicts observed was also drastically reduced. The decrease in conflicts observed at the Leeds sites is in accord with the percentage of encounters and indicates an overall gain in safety.
- The implementations had a very distinct positive effect on the delay for pedestrians. Required waiting times were reduced in all but one location, and in some locations the reductions were quite substantial (e.g. Leeds site 3: from 55 seconds to 22 seconds). This is also apparent in the percentage of pedestrians arriving during the green phase which was increased in all but one location and the percentage of pedestrians who were able to complete the crossing during the green phase which also was increased in all but one crossing.

The disparity in the results obtained in relation to the safety indices is an indication that the possible safety benefits of the implementations are dependent on the situational characteristics of the crossing site. The site that failed to provide any indication of positive effects (Porto site 1) is characterised by an almost chaotic situation with a high and irregular flow of pedestrians and a traffic flow that is often stationary. This makes it almost impossible to prevent pedestrians crossing even when the pedestrian lights are red. Situations that have a relatively high vehicle flow of moving traffic seem better suited for the implementations as realised as is apparent from the reduction in both encounters and conflicts at the Elefsina site and to a lesser extent the Leeds sites.

There is little doubt that the implementations as realised did improve pedestrian comfort. The percentage of pedestrians arriving at green and being able to complete their crossing during green, remains low. There is therefore considerable scope for further improvements.

6 REFERENCES

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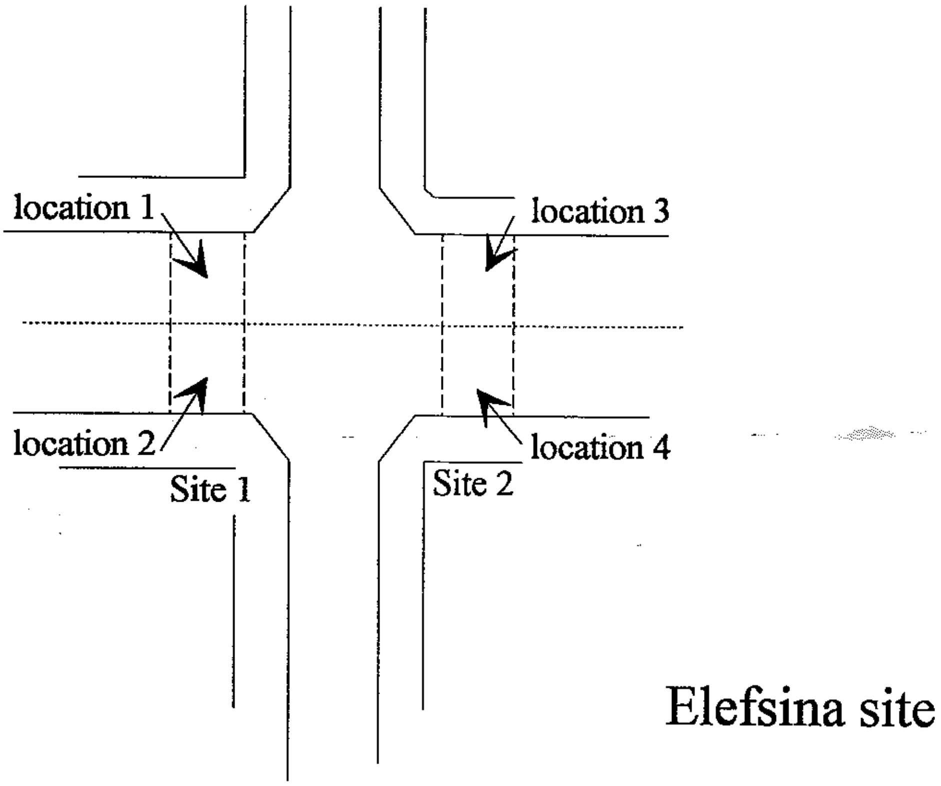
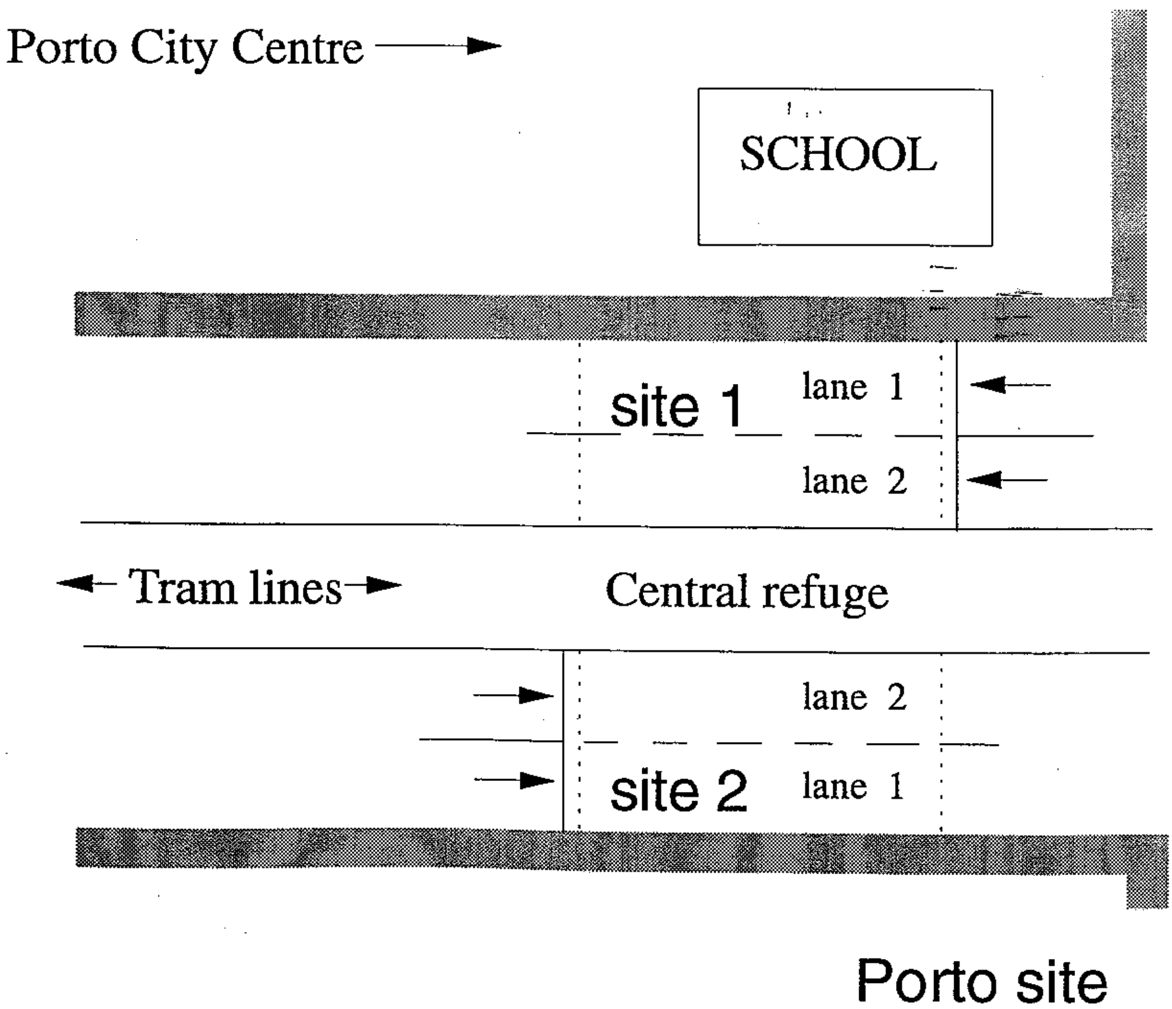
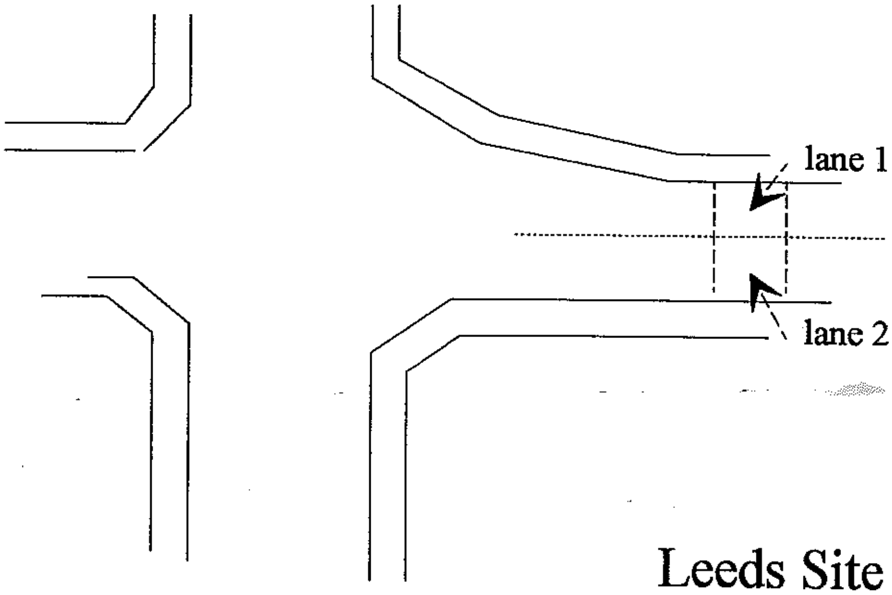
APPENDIX

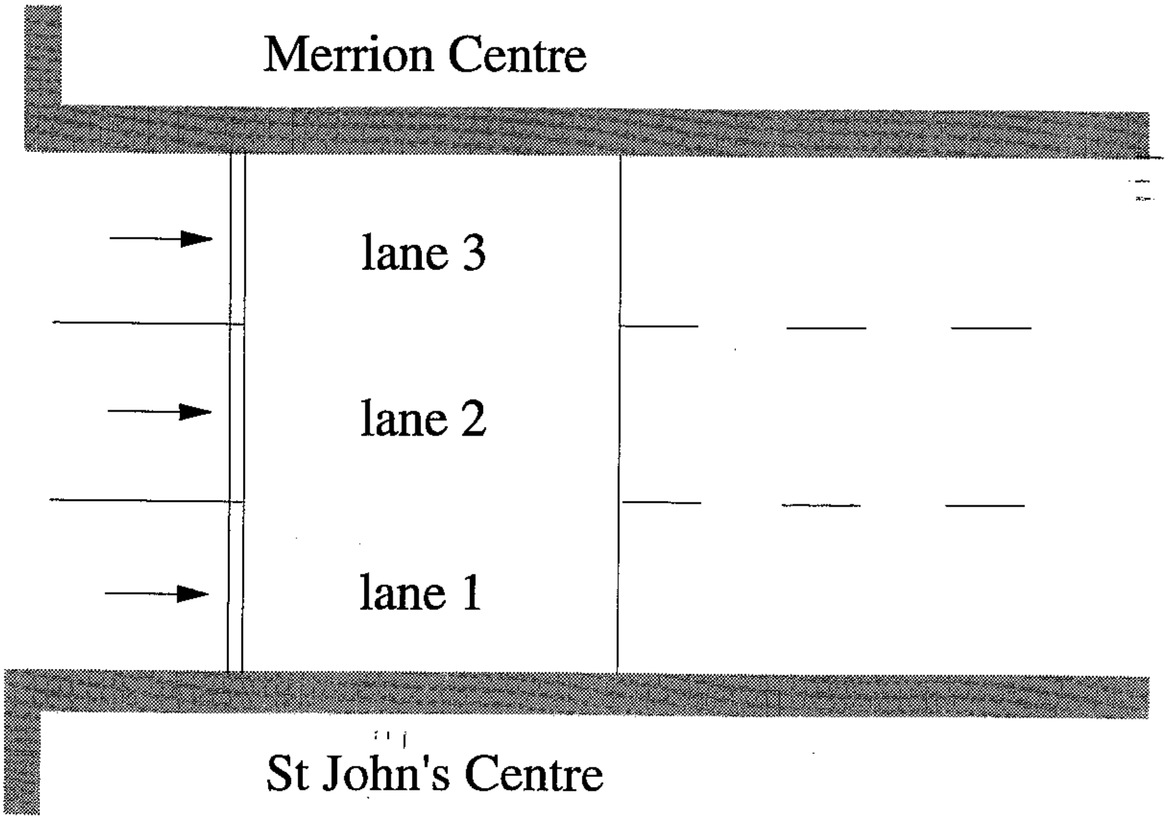
LAYOUT OF SITES


location 1
location 3
location 2
location 4
Site 1
Site 2
Elefsina site


Porto City Centre
SCHOOL
site 1
lane 1
lane 2
Tram lines
Central refuge
lane 2
site 2
lane 1
Porto site



Leeds Site 1



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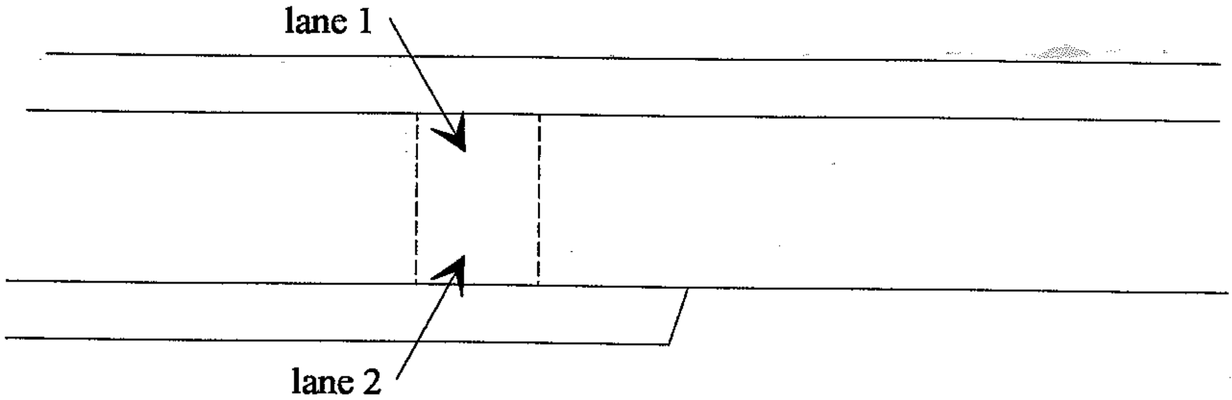
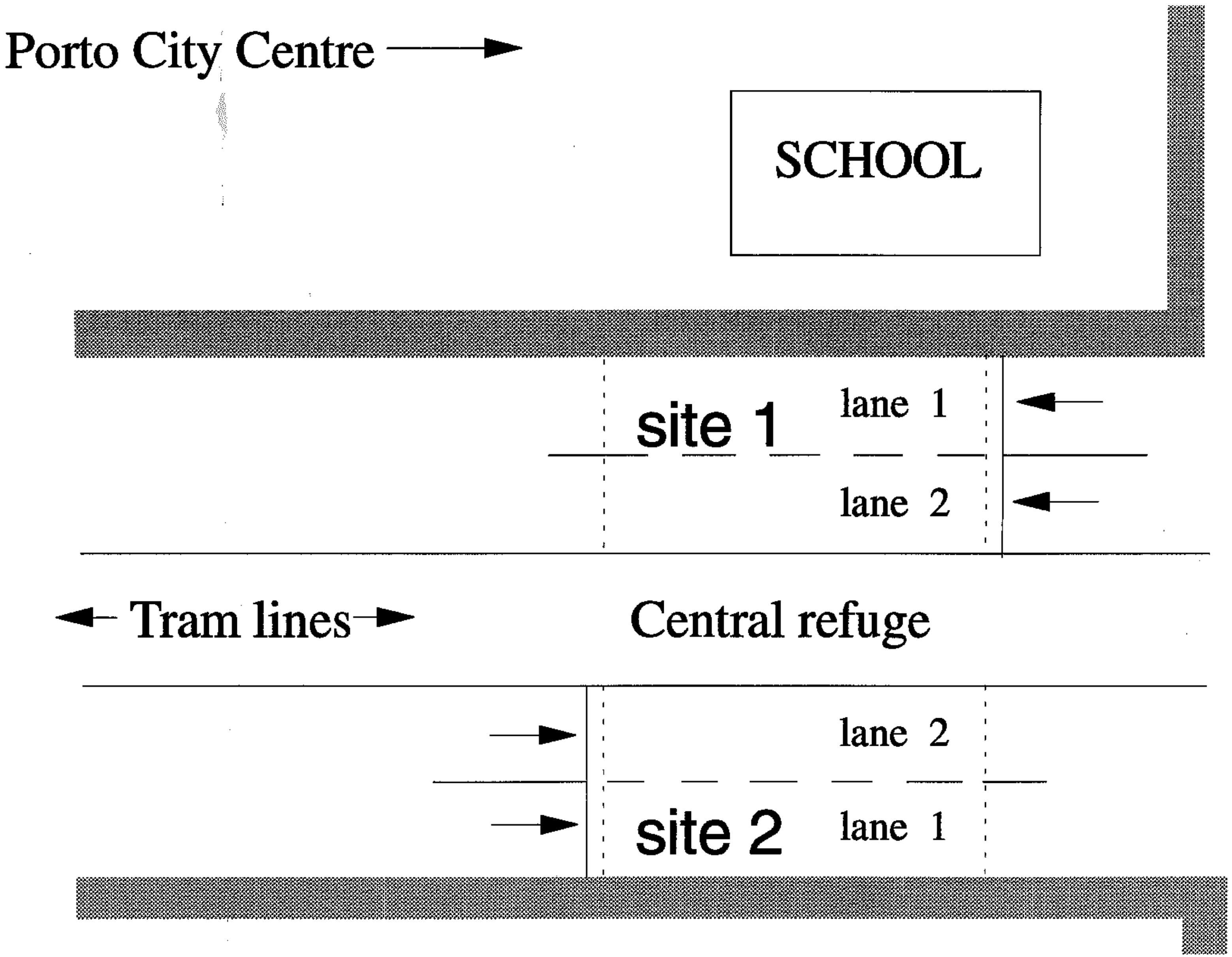
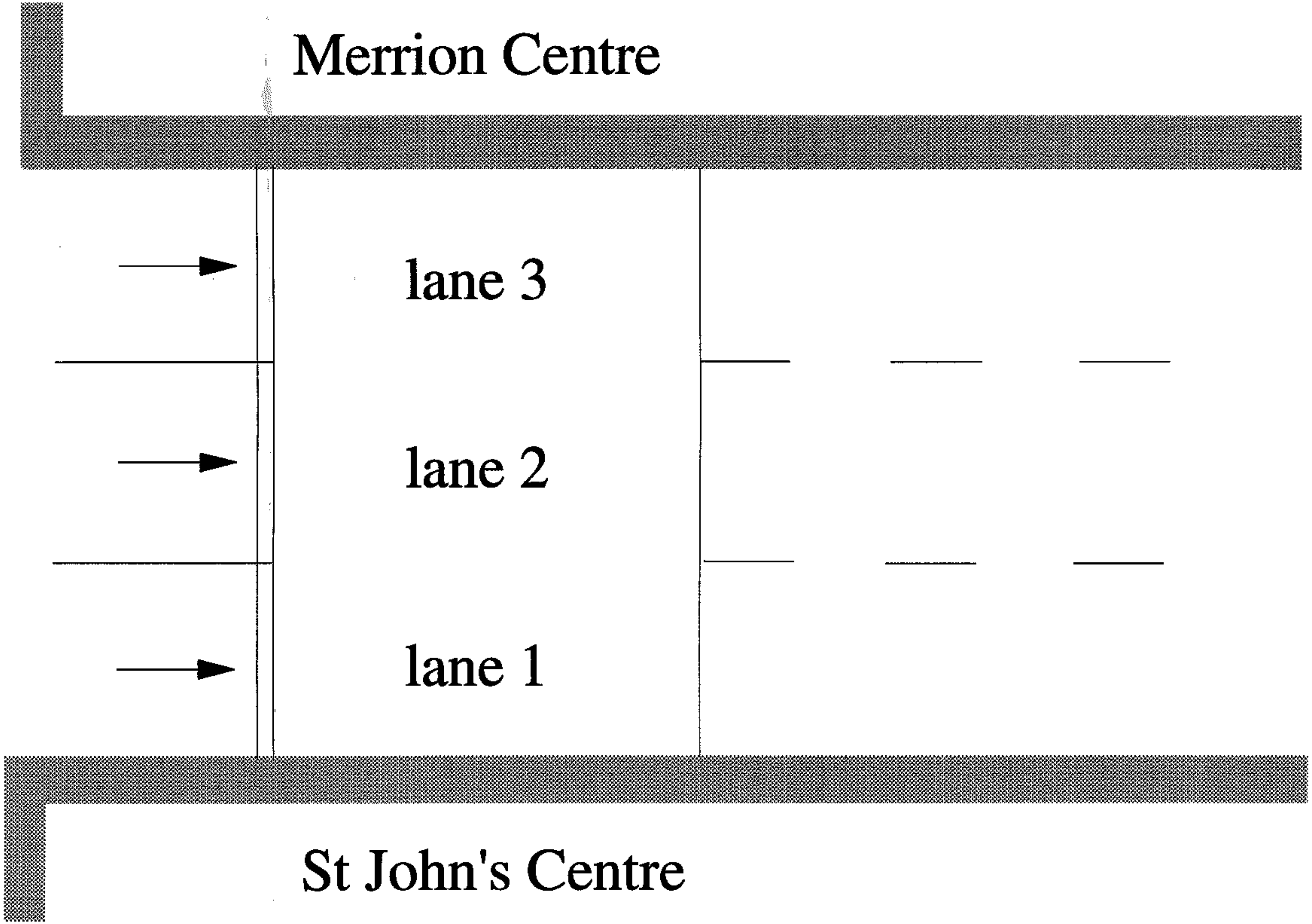


Leeds site 3



Porto City Centre
SCHOOL
site 1
lane 1
lane 2
Tram lines
Central refuge
lane 2
site 2
lane 1

Porto site



Leeds site 2