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THE DEVELOPMENT OF AN AUTOMATIC METHOD OF SAFETY MONITORING AT PELICAN CROSSINGS

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Abstract

This paper reports on the development of a method for automatic monitoring of safety at Pelican crossings. Historically, safety monitoring has typically been carried out using accident data, though given the rarity of such events it is difficult to quickly detect change in accident risk at a particular site. An alternative indicator sometimes used is traffic conflicts, though this data can be time consuming and expensive to collect. The method developed in this paper uses vehicle speeds and decelerations collected using standard in-situ loops and tubes, to determine conflicts using vehicle decelerations and to assess the possibility of automatic safety monitoring at Pelican crossings. Information on signal settings, driver crossing behaviour, pedestrian crossing behaviour and delays, and pedestrian-vehicle conflicts was collected synchronously through a combination of direct observation, video analysis, and analysis of output from tube and loop detectors. Models were developed to predict safety, i.e. pedestrian-vehicle conflicts using vehicle speeds and decelerations.

Keywords: Automatic safety monitoring, pedestrian crossings, conflicts

1. INTRODUCTION

Pelican crossings are now commonplace on roads in the UK. They are essentially signal controlled crossing points where a pedestrian is able, through use of a button, to call a red signal to halt the traffic. Such crossings are generally perceived positively by the public (more so than the main alternative – unsignalised zebra crossings), they have a good overall safety record and are typically installed for safety reasons (see DoT, 1995 for further detail). Despite this, accidents still occur at such crossings and continued monitoring of their safety is important. In Britain in 2002 there were 1584 reported pedestrian injuries in accidents on Pelican crossings (4.1% of total pedestrian casualties (DfT, 2003a)). Much safety monitoring in the UK and many other countries has been carried out using accident frequencies (IHT, 1990a, 1990b, and Zeeger et al, 2002). Because accidents are rare, monitoring requires a long time frame and sometimes, at particular sites, it is impossible to obtain sufficient data for analysis. In addition, the accidents must have already happened before the data can be collected. As one of the aims of monitoring is to give early warning if something is going wrong (IHT, 1997) then time may be lost before a dangerous situation can be rectified. Consequently, there is a need to develop a monitoring method using another safety indicator, which occurs more frequently, and can be used as a proxy for accidents. As safety assessment and evaluation should ideally be made quickly, it is important that the monitoring is undertaken automatically and hence, the safety indicator used needs to be measurable automatically and ideally readily available on site. The aim of this paper is to evaluate the feasibility of developing a simple transferable method for automatic monitoring of traffic safety at Pelican crossings.

This paper reviews and evaluates research which has examined the potential for automatic monitoring of different kinds of safety indicator. It then goes on to describe a method used here to measure safety using vehicle speed and deceleration behaviour from which the occurrence of pedestrian-vehicle conflicts can be determined. The final part of the paper looks at the feasibility of using the methods developed to monitor safety automatically using the standard in-situ loops in place on the approaches to Pelican crossings.

2. BACKGROUND

Probably the most widely used non-accident based safety indicator is traffic conflicts (Perkins and Harris, 1968; Hayward, 1968; Allen et al, 1977 and Hyden, 1987). Traditionally, most traffic conflict techniques either involve direct observations Hyden, 1987; and TRRL, 1987) or are based on video observations (Horst, 1984; Horst and Wilmink, 1986; Jansen et al, 1988; and Tenkink and Horst, 1990). Such techniques are not easily adapted to automatic data collection. Another safety indicator that has been proposed is vehicle deceleration (Balasha et al, 1980; Bonsall et al, 1992; and Hupfer, 1997), which can be collected automatically (Darzentas et al, 1980; Horst and Brown, 1989; and Bonsall et al, 1992). However, none of the data collection methods applied used the standard equipment already available at Pelican crossings. Darzentas et al (1980) used a pair of coaxial cables installed at points 50 metres and 3 metres before the stop line. Horst and Brown (1989) and Bonsall et al (1992) collected deceleration data using instrumented cars, though a large number of such cars is needed to obtain sufficient data for safety monitoring (Bonsall et al, 1992) and this makes the method impractical.

Another problem is that there are no satisfactory models relating vehicle decelerations with other safety indicators such as accident frequencies or conflicts. When proposing vehicle deceleration as a safety indicator, Balasha et al (1980) did not relate it to any safety indicators but defined near accidents where there was rapid vehicle deceleration, that differed from the normal experience. Bonsall et al (1992) developed models to predict accident frequencies using vehicle decelerations. However, as accident data needs to be collected for a long period, the deceleration data and accident data cannot be collected simultaneously. As the vehicle speed and deceleration profiles changed during the study period, Bonsall et al (1992) found that the relationships were not useful. They suggested that changes to the road environment, such as traffic management schemes and traffic calming were the cause of the changes. Consequently, decelerations need to be related to a safety indicator that can be collected simultaneously, such as conflicts.

Hupfer (1997) suggested that Deceleration to Safety Time (DST), the constant deceleration needed to avoid a collision, is a reliable safety indicator in pedestrian-vehicle conflicts. He also proposed four conflict levels using deceleration. However, it is not obvious how he came to these conclusions, and the model relating decelerations to pedestrian-vehicle conflicts was not mentioned.

Given the limitations of the existing work it was felt that a logical progression would be to develop models that examined the relationship between vehicle decelerations (collected from standard loops installed at Pelican crossings) and pedestrian-vehicle conflicts. In order to develop the models, driver reaction (change of speed) during conflicts at Pelican crossings needed to be examined. Similarly, it is necessary to understand something about how pedestrians react when they are involved in conflicts. Previous researchers have studied road user behaviour in conflicts in many situations (Hyden, 1987; Jansen et al, 1988; Horst and Brown, 1989; and Varhellyi, 1998) but not at Pelican crossings, perhaps the nearest being the studies by Tourinho and Pietrantonio (2003) who examined pedestrian conflicts at signalised intersections or Lord (1994) who looked at conflicts between pedestrians and left turning vehicles at signalised intersections.

3. METHOD

3.1 Data collection and transcription

The research was undertaken at a busy main road Pelican crossing in Leeds in the UK. During the five year period prior to the research records showed that there were 6 injury accidents at the site, two of which involved pedestrians. Information on signal settings, road user behaviour and pedestrian-vehicle conflicts were obtained by analysing data collected by direct measurement, video recording and automatic recording using standard ‘system D’ loops. These are 3 in-situ loops (x, y and z) designed to detect vehicle presence and installed respectively at points 39m, 25m and 12m upstream from the stop line of the crossing.

Three additional pairs of pneumatic tubes were installed on the approach to the crossing. The tubes were needed for 3 reasons:

- The data loggers linked to the xyz loops could not calculate vehicle speed over each loop. This problem was overcome by putting down a pair of pneumatic tubes 1 metre apart (called T12 here) on top of the z loop, as shown in Figure 1.

Figure 1 about here

- Vehicle speed and deceleration data were needed in advance of the x loop to examine aspects of driver behaviour approaching the loops. Tubes were put down at 57m and 56m before the stop line. These points were chosen because they were far enough from the Pelican that the speeds were not influenced by activities on the crossing. According to Darzentas (1980) and Varhellyi (1998) usually drivers do not decelerate before these points. Furthermore, at these points there were lighting columns at which the data logger and its box could be chained and locked.
- An additional pair of tubes was needed to record vehicle speeds close enough to the stop line so that driver behaviour between the z loop and the stop line could be recorded. Tubes were put down at points of 4m and 3m before the stop line. These points were chosen so that almost all stopping vehicles crossed these tubes and their speeds could be recorded.

Two video recorders were placed on the roof of an adjacent tall building. The first was to collect pedestrian and vehicle data in the vicinity of the crossing. This included the time each vehicle arrived at each loop or tube when approaching the crossing, the lane(s) used by the vehicle, and pedestrian crossing behaviour away from the crossing. The second camera was to collect signal settings, pedestrian behaviour and driver behaviour at the crossing. The locations were sufficiently high to prevent obstruction of view by large vehicles such as buses.

The data from video were transcribed using the VIDS and PROGRESS programs (Marsden, 1995). The VIDS program was used to transcribe signal setting data (especially the beginning of the green for pedestrians period), pedestrian data (pedestrian step-off times and arrivals from which average walking speed was calculated), and vehicle flow; while the PROGRESS program was used to track the passage of each vehicle crossing the loops and tubes. The programs are able to record events with an accuracy of a hundredth of a second. The VIDS program can record up to two events (such as the time a vehicle arrives at point 1 and the time a vehicle arrives at point 2) simultaneously as many times as required. For each event up to six categories can be applied, such as motorbike, car, light goods vehicle, heavy goods vehicle, bus and other. The PROGRESS program can record more than two events but only once for every record. Each event can also be divided into up to six categories. In this research the VIDS program was used to record either one or two events with up to two categories, while the PROGRESS program was used to record six events with six categories.

3.2 Detection of the presence of pedestrian-vehicle conflicts

Hyden (1987) developed the following definition of a traffic conflict:

> *“A conflict is either an event that would have led to a collision if both road-users had continued with unchanged speeds and directions or a near-miss situation where at least one of the road-users acts as if they were on a collision course”.*

This importantly expanded upon earlier definitions to allow for the inclusion of near misses. Hyden’s method bases a conflict on the time to accident if the speed and direction of the participants remained unchanged. An alternative approach is using Post Encroachment Time (PET) which in this context is the difference between the moment a pedestrian leaves the area of potential collision and the moment of arrival at the potential collision by the conflicting vehicle possessing the right of way (Cooper, 1984).

For this research the occurrences of pedestrian-vehicle conflicts were initially detected using PET. Usually, in a pedestrian-vehicle conflict at this site, one vehicle was involved with more than one pedestrian as the presence of the signals tended to group pedestrian crossing actions. Furthermore, when a vehicle decelerated, the vehicles behind were forced to decelerate. The data were grouped into time intervals of one minute that was similar to the cycle time of the Pelican crossing. Models were then developed to relate the severity of conflicts with vehicle speeds and decelerations. During piloting it was found that it was also possible to relate vehicle speeds and decelerations with TA (Time to Accident). Eventually the occurrence and the severity of conflicts could be detected by using vehicle speeds and deceleration.

4. BEHAVIOUR OF ROAD USERS INVOLVED IN PEDESTRIAN-VEHICLE CONFLICTS

In an ideal situation there would be no conflicts at a signal controlled crossing such as a Pelican. However, at this site conflicts occurred both as a result of driver and pedestrian non-compliance with the light settings. Most driver non-compliance occurred during the flashing amber to drivers period (i.e. drivers should not proceed unless the crossing is clear of pedestrians) – this accounted for 23.3 per cent of the conflicts in the morning and 21.4 per cent in the afternoon. The other key period for conflicts was during the green for drivers phase when 51.4 per cent of the conflicts in the morning occurred and 61.0 per cent in the afternoon. This latter group of conflicts is likely related to the delays experienced by pedestrians (50 per cent of pedestrians experience signal-imposed delays of more than 27 seconds).

The current research found that when there were pedestrian-vehicle conflicts almost all drivers decelerated and pedestrians walked faster or ran. When vehicles and pedestrians involved in conflicts were matched individually, it was found that almost all (i.e. 98 per cent) of the drivers took action by decelerating between the y and z loops. There was agreement between this finding and Hyden (1987) who found that in pedestrian-vehicle conflicts 93.1 per cent of actions taken by drivers included braking (79.1 per cent of them were braking only and 14.0 per cent were a combination of swerving and braking). Hyden (1987) also found that there was similarity between the actions taken by drivers involved in conflicts and by those involved in accidents. In pedestrian-vehicle accidents, 86.6 per cent of drivers decelerated (this consisted of 67.1 per cent who decelerated only and 19.5 per cent who both swerved and decelerated).

Varhellyi (1998) discovered that when there were pedestrian-vehicle conflicts at a Zebra (non-signalised) crossing, drivers started to decelerate at points between 60 and 15m from the crossing. This differed from the current research on Pelicans which showed that drivers started to decelerate at points between 25 and 12m. This might be because at Zebra crossings pedestrians stepping off the kerb have the right of way and drivers would prepare to decelerate or stop, while at Pelicans the need to stop is governed by a signal which can be seen well in advance. Varhellyi (1998) did not draw a relationship between the decelerations and the severity of conflicts so it could not be concluded which decelerations related to which conflicts.

Jansen et al (1988) found that in traffic conflicts at priority junctions, drivers started decelerating between 25m and 28m upstream of the stop line, whereas Horst and Brown (1989) found the distances were between 15m and 38m. The result of the current research is similar to that of the first study but not to the second one. The first study was undertaken in the real world, i.e. at priority junctions; while the second one was a simulation of rear-end vehicle-vehicle conflicts and the drivers were aware that at a certain point there was a static vehicle that needed to be avoided.

Howarth's (1985) finding was also similar to that found in this research. He found that most drivers took avoiding actions only within 20 metres of a child pedestrian who was intent on crossing the road, too late to comfortably avoid a collision if the child continues on their course.

5. MODELING SAFETY

5.1 Relationship between vehicle approach speed and vehicle deceleration

This research found that when drivers involved in conflicts approached the Pelican at higher speeds, they decelerated harder. This finding was similar to those of Horst and Wilmink (1986), Jansen et al (1988) and Horst and Brown (1989). For a given point, in this case 25m before the stop line, higher approach speeds will lead to more serious conflicts because the TA values (i.e. distance divided by speed) will be lower. Furthermore, according to Hyden (1987), similar TA values with higher speeds lead to more severe conflicts because higher approach speeds increase the likelihood of vehicle control problems.

5.2 Deceleration rates as a safety indicator

It was found that there was a strong relationship between vehicle deceleration and the severity of conflict for those vehicles with a high approach speed, i.e. not less than 37 km/h. The data are shown in Figure 2 and the relationships developed are presented in Equations 1 and 2 for linear and compound models respectively.

$$mTAh = 2.437 - 0.147\ mdh25\text{-}12 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$\text{Ln}\ (mTAh) = 0.904 - 0.073\ mdh25\text{-}12 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where:

mTAh: mean Time to Accident in seconds with high vehicle approach speed,

mdh25-12: mean vehicle deceleration in m/s^2 (between the y loop and the z loop) with high approach speed ($\geq$ 37 km/h).

Figure 2 about here

On the basis of this data, it is concluded that deceleration rates in this context are a valid safety indicator. The severity of conflicts was determined by relating the deceleration rates (mdh25-12) and Time to Accident (mTAh) values based on the models as presented in Table 1. When establishing the severity, comparisons with previous studies were also made.

Table 1 about here

It can be seen from Figure 2 and Equation (1) that a deceleration of 6m/s^2 is similar to an mTAh value of 1.6 seconds. Hyden (1987) defined a serious conflict as one with a TA value of 1.6 seconds with an approach speed of not less than 40 km/h. Hyden (1987) did not determine the thresholds between slight and potential conflicts or between potential conflicts and normal encounters so these thresholds could not be compared with the results of this research.

Bonsall (1992) showed that the number of decelerations of over 5m/s^2 was related to the number of accidents (although the relationship was less indicative for more recent accidents). Williams (1977) determined 3m/s^2 as a threshold of comfortable decelerations, Horst (1990) and Bonsall (1992) suggested 3m/s^2 as a threshold between normal and abnormal decelerations and AASHTO (2004) use a deceleration rate of 3.4m/s^2 as a standard design deceleration. When drivers decelerate at a rate that is not comfortable for them, it indicates that they did it to avoid collision. However the 3m/s^2 deceleration rate was much lower than 6m/s^2 so it was reasonable to suppose that the severity of the conflicts were much less serious. Deceleration of 4.5m/s^2 is between 3 and 6m/s^2 and for this work it was thought reasonable to determine 4.5m/s^2 as a nominal threshold between potential and serious conflicts.

Hupfer (1997) suggested 4 deceleration thresholds for various severities of pedestrian-vehicle conflicts. This work had similarity to the current research as he used deceleration as an indicator to determine the severity of conflicts by assuming that the decelerations were constant. However, there are large differences between his findings and those of this research as explained below.

Firstly, Hupfer (1997) used Deceleration to Safety Time (DST) while this research used mdh25-12. DST was calculated for individual vehicles while mdh25-12 was the mean deceleration for all vehicles decelerating during the flashing amber and green to drivers periods in a one-minute interval.

Hupfer's DST was calculated using Equation 3.

$$\text{Deceleration}_{ijk} = \frac{2(S_{jk} - V_{ij} t_{ijk})}{t_{ijk}^{2}} \ldots\ldots\ldots\ldots\ldots (3)$$

Where:

Deceleration$_{ijk}$ =deceleration of vehicle i between points j and k (m/s^2)
S$_{jk}$ = distance between point j and k (metres)
V$_{ij}$ = speed of vehicle i at point j (m/s)
t$_{ijk}$ = how long to travel from point j to point k for vehicle i (seconds)

In this current research mdh25-12 was calculated based on Equation 4 and for approach speeds of not less than 37 km/h.

$$\text{Deceleration}_{ijk} = \frac{V_{ik} - V_{ij}}{t_{ijk}} \ldots\ldots\ldots\ldots\ldots (4)$$

Where:

V$_{ik}$ = speed of vehicle i at point k, m/s

When deceleration is constant the values calculated from the two equations are equal, however in real life Wortman (1994) found that constant decelerations were unlikely, especially for approach speeds below 45 km/h and above 100 km/h (the ratio would be around 0.5 and 1.5 respectively). Equation 4 would always result in decelerations greater than those obtained from Equation 3.

Secondly, Hupfer (1997) divided the severity of conflicts into 4 deceleration thresholds of 1, 2, 4 and 6m/s^2 with 1m/s^2 as a threshold of normal encounters and 6m/s^2 as a threshold of the most severe conflict. However, it was not clear how these conclusions were arrived at. Furthermore, the study did not mention the relationship between deceleration and any other safety indicator such as accidents, PET or TA. This is an important drawback of the method. Similarly, Balasha (1980) was criticised for defining thresholds of normal and abnormal encounters without relating them to any safety indicators. The research reported here determined the severity of conflicts by relating deceleration with TA.

Finally, Hupfer (1997) did not mention how decelerations were measured so that it was not possible to compare with the method used in this research.

6. AUTOMATIC MONITORING OF SAFETY AT PELICAN CROSSINGS

6.1 Automatic monitoring: is it possible?

It was not possible to develop and test a fully automatic method of safety monitoring at Pelican crossings because data loggers capable of recording deceleration automatically were not available at the time of the research. However data which can be used to calculate decelerations are already recorded by existing data loggers and hence it is felt that the methods described here are technically feasible in the near future. Automatic monitoring could be undertaken in the following stages using standard loops (i.e. a pair of speed measurement loops), yz loops and data loggers that have a program to calculate vehicle deceleration:

Stage 1: The speed measurement loops measure the combined length of each vehicle, $Lc_{i,}$ (i.e. length of vehicle + loop field length). The yz loops measure time occupancy of each vehicle (Δt_{ij}).

Stage 2: The speed of each vehicle passing loops y and z is calculated using Equation 6.

$$Speed_{ij} = \frac{Lc_i}{\Delta t_{ij}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (6)$$

Where:

$Speed_{ij}$ = speed of vehicle i across Loop j

Lc_i = combined length (length of vehicle + loop field length) of vehicle i in metres

Δt_{ij} = time occupancy of vehicle i crossing Loop j in seconds (obtained from Loop j)

Stage 3: Vehicle deceleration between the loops can be calculated using Equation 4.

In future, it should also be possible to undertake automatic monitoring using two single loops, i.e. the yz loops. This will happen if programs to predict vehicle speeds (by predicting Lc_i and measuring Δt_{ij}) together with that to calculate vehicle decelerations between two points are available for data loggers. Existing data loggers for loops can produce loop time occupancy for each vehicle crossing a single loop (Δt_{ij}) and vehicle type.

6.2 When and where are the techniques applicable?

Because such methods use vehicle decelerations as an indicator of the severity of pedestrian-vehicle conflicts, care should be taken that any decelerations that do not relate to the activity at the Pelican crossing are not included. For instance: any congested lanes, any lanes having side roads within 25m of the stop line or bus lanes with bus stops along them. As the models were developed using data collected from a Pelican crossing within an Urban Traffic Control (UTC) system with a cycle time of 60 seconds, further study would be needed to validate the models for Pelican crossings with different cycle time or operation.

Table 2 shows the range of data used to develop the models. Vehicle flow was between 360 and 1140 vehicles/hour and the range of pedestrian flows was even wider, i.e. between 60 and 2220 pedestrians/hour. Vehicle speeds ranged from 37 to 70 km/h. Pedestrian speeds were between 1.03 and 4.26m/s. It should be noted that pedestrian speeds included all pedestrians, not just those involved in pedestrian-vehicle conflicts.

Table 2 about here

The methods used here should be applicable to streets with any number of lanes as long as there are no vehicles changing lane between 25m and 12m before the stop line. However, further study should be undertaken to check whether the method is applicable in streets with different lane configurations. Special care should be taken where vehicles straddle more than one lane as this could invalidate any results.

6.3 Collection of data

Data can be collected in 3 ways, according to equipment availability. These are shown in Figures 3-5.

The first method (Figure 3) uses 2 loops, i.e. the yz loops put down at points of 25 and 12 metres respectively before the stop line and a set of speed measurement loops 79 metres from the stop line.

Figure 3 about here

The second method (Figure 4) uses 2 loops, i.e. the yz loops and a pair of tubes (T12) put down on top of the z loop.

Figure 4 about here

The third method (Figure 5) uses 2 pairs of temporary tubes, i.e. T25 and T12 which are put down at points 25 and 24 metres; and 12 and 11 metres respectively from the stop line.

Figure 5 about here

The loops mentioned above are parts of standard xyz loops, while the speed measurement loops are usually installed on roads where 85th percentile vehicle speeds are higher than 56km/h (DfT, 2003b).

According to TRRL/IHT (1987), conflict data needs to be collected over three weekdays in order to get sufficient data for safety monitoring. Data are typically collected between 08.00 and 18.00 to provide information on peaks and off peaks, however it is usually not as easy to collect information during the hours of darkness. The methods used here, based on deceleration data, mean it is possible that monitoring can be undertaken in darkness.

It is very important that data for the same set of vehicles are collected at points 25 and 12m before the stop line. In order to achieve this, the first vehicle and the last vehicle recorded at both points must be the same.

6.4 Data analysis

The data loggers used with Layout 1 (Figure 3) record the time a vehicle activates each loop, the combined length of each vehicle (Lc_i), vehicle speeds at a point 79 metres before the stop line and the time each vehicle occupies the loop. Vehicle speeds at the yz loops are calculated using Equation 6.

The data logger for the loops in Layout 2 (Figure 4) records the time and loop time occupancy for each vehicle. The data logger for the tubes records the time each vehicle hit the first tube and the vehicle speed over the tubes. The combined length of each vehicle (Lc_i) is calculated using Equation 7 and vehicle speeds at the y loop are calculated using Equation 6.

$$Lc_i = \frac{Speed_{i,y}}{\Delta t_{i,y}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Where:

$Speed_{i,y}$ = speed of vehicle i across the y loop in m/s (obtained from T12)

$\Delta t_{i,y}$ = how long vehicle i occupied the y loop in seconds (obtained from the y loop)

The data loggers used with Layout 3 (Figure 5) automatically record speed data.

Decelerations of each vehicle between points 25 and 12 metres before the stop line are calculated using Equation 4. A set of vehicles is then chosen, i.e. those which decelerate between points 25 and 12 metres before the stop line with approach speed at the 25 metres point of not less than 37 km/h, during the green and flashing amber to driver periods. Mean deceleration for each 1-minute interval (mdh25-12) can then be calculated.

The severity of conflicts can be determined using the thresholds presented in Table 1. The results of the monitoring includes figures for the number of minutes (in both the morning and afternoon periods) within a one hour period which have mean decelerations (and hence conflicts) of particular severities as shown in Table 3.

Table 3 about here

6.5 How to interpret the results

Two techniques can be used to interpret the safety level of a Pelican crossing. The first is by comparing the number of minutes having serious, slight and potential conflicts at a Pelican crossing with other similar Pelican crossings. The second one is by comparing the number of conflicts before and after the implementation of a measure to improve safety. According to IHT (1990b) safety monitoring can be carried out by comparing the number of accidents occurring for a number of years (usually 5) before the implementation, during the implementation and a number of years (usually 2) after the implementation; or 5 years before and 5 years after the implementation. The long period required is due to the low freqency of accidents. Monitoring using vehicle deceleration can be undertaken in a much shorter period over a few days. In this research it was found that the safety problem at the Pelican was more severe in the afternoon than that in the morning. As seen from Table 3 serious, slight and potential conflicts (based on mean deceleration in each one minute period) occurred during 2, 3 and 9 minutes respectively in a one hour period in the afternoon; while in the morning there were no serious conflicts and slight and potential conflicts occurred during 4 and 11 minutes respectively in one hour of monitoring. Given lack of comparable data for other crossings it is not possible to conclude whether these figures represent a good or a poor safety record. Several researchers have indicated that accident risk is only reliably correlated with serious conflicts (Svensson, 1998 and Tourinho and Pietrantonio, 2003) and that therefore slight and potential conflicts should be omitted from the analysis.

7. CONCLUSIONS

When involved in conflicts at a Pelican crossing, both pedestrians and drivers took evasive actions. Pedestrians took action by walking faster or running. Ninety eight per cent of vehicles involved in conflicts decelerated between points 25m and 12m before the stop line. It was found that the higher the vehicle approach speeds, the higher the vehicle decelerations and that there was a good relationship between vehicle decelerations and time to accident, in particular it was concluded that severity of conflicts could be determined using deceleration rates. It was also shown that it is possible to develop a fully automatic method of safety monitoring at Pelican crossings using standard loop configurations. Further development of the methods and the models needs to be undertaken, so that they can be used in a more general situation, and as a complement to existing monitoring techniques using accident frequencies. Furthermore, when the use of accident frequencies is impossible such as in a short-term evaluation, the methods developed here can be used as an alternative.

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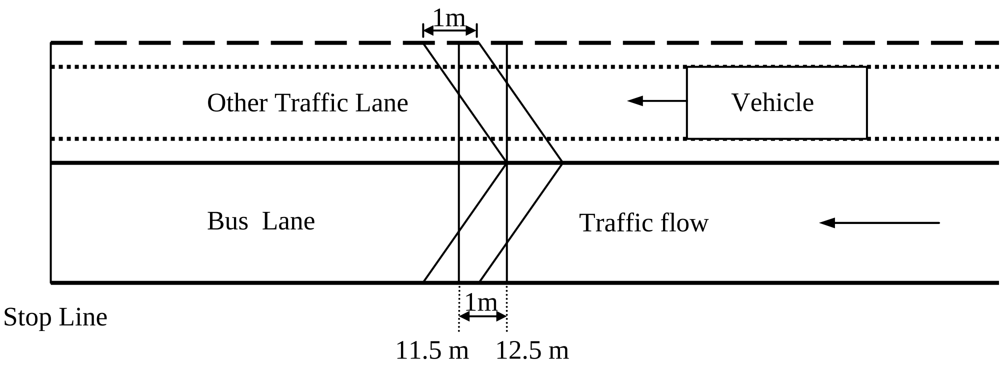
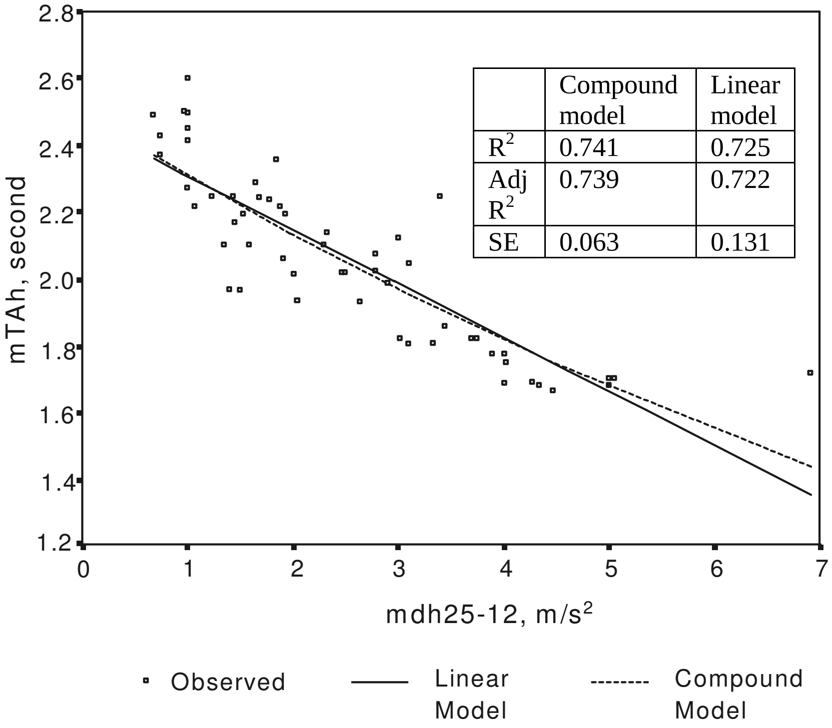


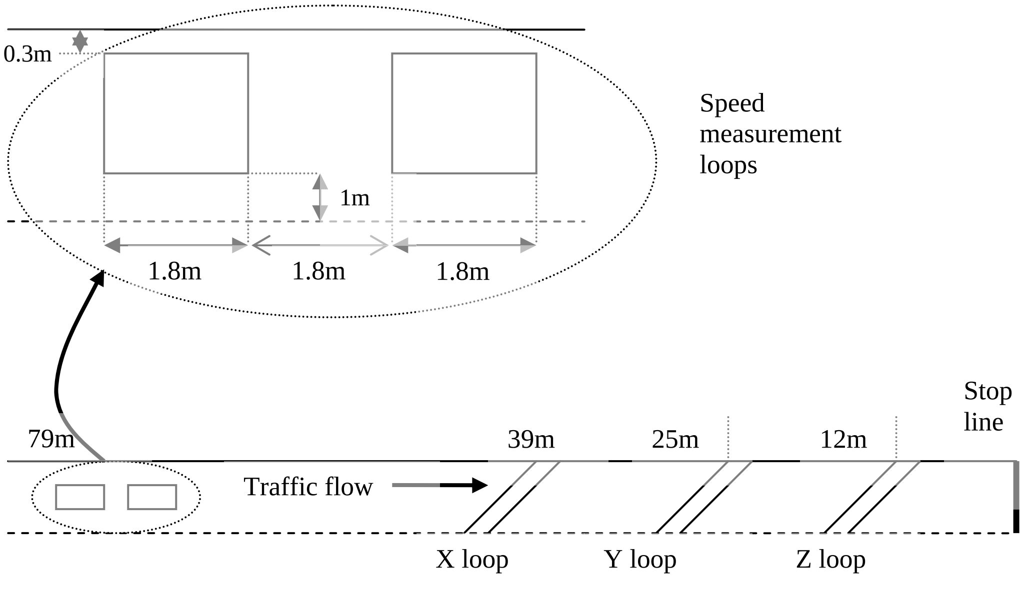
Note: the Distances are measured from the stop line; not to scale

Figure 1. Pneumatic tubes location (T12) in relation to the z loop (L12)



	Compound model	Linear model
R^2	0.741	0.725
Adj R^2	0.739	0.722
SE	0.063	0.131

Figure 2. Predicted mTAh (seconds)



Note: not to scale

The bus lane is not shown in this and subsequent diagrams and hence the x, y and z loops are shown as half of the chevrons in Figure 1

Figure 3. Equipment Layout 1: xyz Loops and Speed Measurement Loops

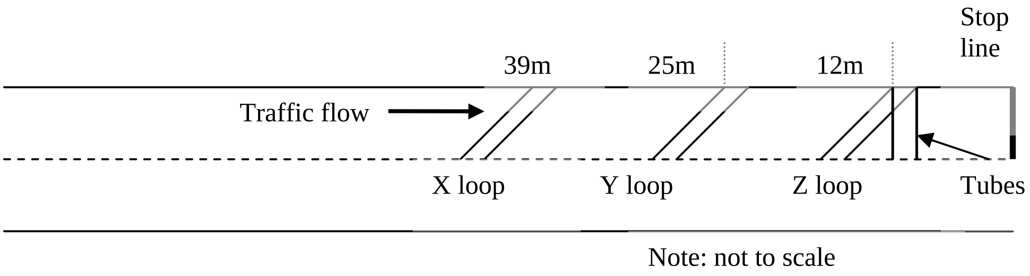
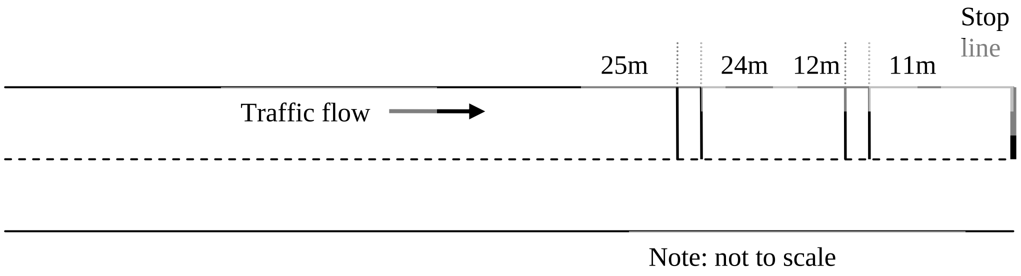


Figure 4. Equipment Layout 2: xyz Loops and T12



Figures 5. Equipment Layout 3: T25 and T12

Table 1. Thresholds of Various Severity of Pedestrian-Vehicle Conflicts by Deceleration and Time to Accident

Deceleration	Time to accident (second)		Severity
(m/s^2)	Linear Model	Compound Model	of Conflict
6.0	1.6	1.6	serious
4.5	1.8	1.8	slight
3.0	2.0	2.0	potential

Table 2. Range of Data Used in Modeling[a]

Variable	Minimum	Maximum	Mean	Standard Deviation
Vehicle Flow (veh/hour)	360	1140	706	184
Pedestrian Flow (ped/hour)	60	2220	933	438
Vehicle Speed (km/h)	37	70	51	10
Pedestrian Speed (m/s)[b]	1.03	4.26	1.77	0.47

[a] the data were calculated using a 1-minute interval

[b] for all pedestrians, not only those involved in conflicts

Table 3. Examples of Results of Safety Monitoring at the Pelican Crossing

Mean Deceleration (mdh25-12 (m/s2)) in each minute period	Severity category of Ped-Veh Conflicts	Number of Minutes in One Hour with conflicts: Morning	Number of Minutes in One Hour with conflicts: Afternoon
≥ 6	Serious	0	2
≥4.5 - 6	Slight	4	3
≥3 - 4.5	Potential	11	9