PHYSIOLOGICAL MEASUREMENT OF RISK PERCEPTION OF PEDESTRIANS IN PASSING TRAFFIC

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Abstract

This paper describes a modeling framework and data collection process to investigate stressful situations experienced by road users in typical residential streets in Japan. The level of risk perception as experienced by pedestrians sharing a road with motor vehicles is investigated by using a physiological symptom. This model is a tool useful to evaluate the effects of traffic management policies.

INTRODUCTION

The interactions among different types of road users are known to cause stresses to the weak and small in the traffic stream just as the 'law of the jungle' dictates that the small creatures live in fear of the large. It is important that the planners have an understanding of this phenomenon in the context of local roads and possess necessary tools and technique to account for such interactions. In this study, residential streetscape in Japanese cities is investigated to observe such interactions and stresses.

Streets in residential areas are an extension of the living space for inhabitants and seemingly casual movements of non-motorized road users such as pedestrians and cyclists. However, there is a major dilemma for planners as this space is also used by motorized traffic. This environment is further degraded by on-street parked vehicles and bicycles, in addition to motor cars using these streets for through traffic purposes to avoid the traffic congestion on arterial roads. In Japan and many other Asian cities, this space is even further congested because of the narrowness of street width which has been further reduced by roadside furniture such as utility poles, traffic signs, vending machines, fire hydrants and post boxes. Figure 1 shows typical streetscape from Saga City, Japan, to illustrate the lack of sense of safety and comfort for pedestrians and cyclists. In this environment, the non-motorized road user is required to maintain an acute level of alertness and be prepared to take evasive action frequently for self-preservation.

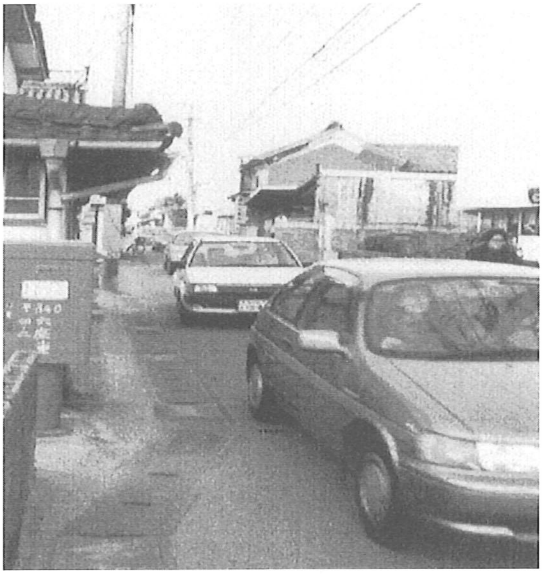

Figure 1 Traffic conditions in a typical residential street in Saga City

A popular methodology to assess the level of safety is the use of direct questionnaire surveys. There are a number of previous studies concerning the safety of residential streets based on the questionnaire surveys (Hino and Yamanaka, 1996; Nishimura and Hino, 1988; Ogino *et al.*, 1990; Takai and Nishimura, 1985; Yamanaka and Mitani, 1996). However, the reliability of questionnaire methodology in this area is typically low because of the need to rely on respondent memory about various events during a particular walk trip. It has been identified that there is a need to develop direct observation methods to assess the level of perceived safety. As a result, as shown in Kiyota *et al.* (1995), some researchers have attempted to use the spacing maintained by non-motorized traffic as an indicator of the level of safety. Such methods make use of the observation that pedestrians and cyclists, i.e., non-motorized traffic, generally attempt to keep away from passing automobiles in response to the level of risk perception. Therefore, it is possible to estimate the level of risk perception by means of observing the behavior of non-motorized road users, and the buffer zone maintained by them against the passing automobiles (Kiyota *et al.*, 1995). However, such methods are also prone to experimental errors and may not reveal the accurate level of risk perception as some may not be able to keep away from the passing vehicles in the usual manner because of various forms of restrictions.

The method developed in this study is based on the measurement of a physiological feature which signifies that a person is under stress. The rate of heartbeat of pedestrians is the selected physiological feature to monitor the level of risk perception. The rate of heartbeat is a robust indicator of level of stresses such as danger and irritation. In association with this measurement method, a model has been developed to predict the level of risk perception of pedestrians in passing traffic based on fluctuations of the pulse rate and traffic conditions such as traffic speed, density, the type of passing and the type of vehicles. This is a model useful in evaluation of effects of the traffic policies such as the reduction of traffic speed and widening of streets intended to improve the amenity and traffic throughput.

LEVEL OF SAFETY EXPERIENCED BY PEDESTRIANS

There are residential streets in Japan which are risky for pedestrians and cyclists as already shown in Figure 1. These roads are especially risky for the elderly and children because of their narrow width and relatively high speed of through traffic. Traffic accidents on residential streets are increasing. Conflicts between motor vehicles and pedestrians occur more frequently on residential streets though not resulting in traffic accidents. Consequently, residential streets have lost their original character, their social function and their role in providing facilities for the weaker road participants. The function of catering for motor vehicles becomes the dominating role for these streets and therefore has major environmental implications. For example, emissions and noise gradually degraded the quality of the adjacent residential area. And the surrender to motorized traffic results in the society paying a high price in terms of fuel consumption.

In order to improve road safety and create livable streets many traffic management measures such as Woonerven, traffic calming and speed zoning have been applied in cities in the Netherlands, German and England (Hass-Klau, 1990). For example, the 30 kmph's speed limit has been introduced in many residential areas to reduce the speed of motor vehicles. What is not apparent, however, is whether there is a significant reduction to the perceived level of risk against passing motor vehicles at a speed of 30 kmph. This paper attempts to provide modeling tools required to assess such traffic management measures.

The main outcome of the project reported in this paper is a model that allows prediction of the level of risk perception of pedestrians sharing the road with passing motor vehicles. In developing this method, physiological measurements were obtained from subjects negotiating residential streets along with other traffic data. The focus of the physiological measurement of stressful road experience of the subjects in this research project has been their rate of heartbeat. The heartbeat of the subjects varied according to the conditions faced by them, and a portable method has been devised to allow accurate measurements.

MEASUREMENT

Measurement technique

There are several ways to monitor the psychological stresses such as risk situations, irritations and nervousness. These methods are based on the measurement of physiological clues such as changes in blood pressure, heart rate, respiration, perspiration and the galvanic skin response. A symptom that can be easily measured and does not require large-scale equipment is sought in order to measure the psychological stress as revealed by the physiological response to the ever-changing external stimulations. It is the traffic condition that acts as the stimuli here. The rate of heartbeat was found a suitable physiological symptom to measure the level of stress. This is a symptom that varies with the level of stimuli applied. Also, heartbeat is an involuntary feature as far as an individual is concerned. Heartbeat rate signifies the number of pulses per minute that the ventricle of heart undergoes its pumping action. These pulses are obtained in the field study by the count of the number of R-waves on an electrocardiogram. The interval between two continuous R-waves is measured to compute the heartbeat rate per minute.

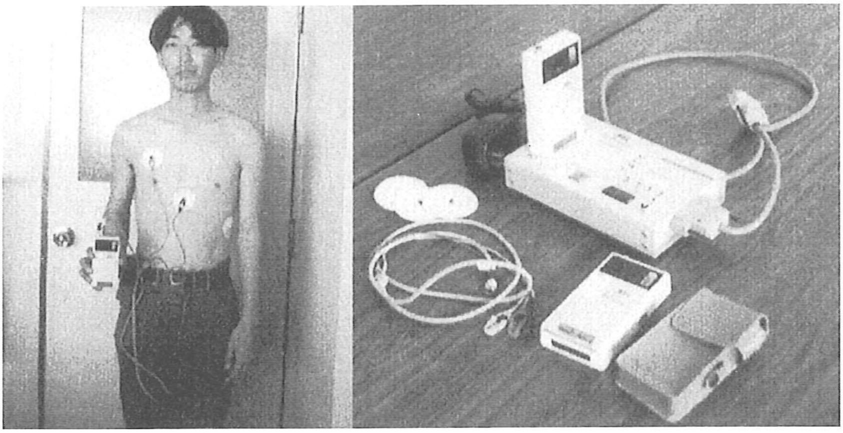

Figure 2 A pedestrian subject with the potable monitoring equipment

The portable monitoring equipment used in this study has been adopted from conventional medical equipment based on a semiconductor storage cell as shown in Figure 2. Its storage capacity is 12 kilo bytes and allows recording for 3.6 hours when the ventricle of heart pulses at a rate of 60 times per minute. The upper bound of pulse rate that can be measured using this device is 225 per minute. That limit is quite adequate for the purpose of this project. The weight of the device is 170 grams. The lightness of the equipment (shown in Figure 2) is important as the subject was asked to wear the device on his (all subjects used were males) trouser belt. Figure 3 shows the output of the rate of heartbeat as indicated on a display. This shows the fluctuation of the rate of heartbeat computed based on R-waves mentioned before. The data stored in the mobile unit was directly transferred to a microcomputer at the end of each experiment.

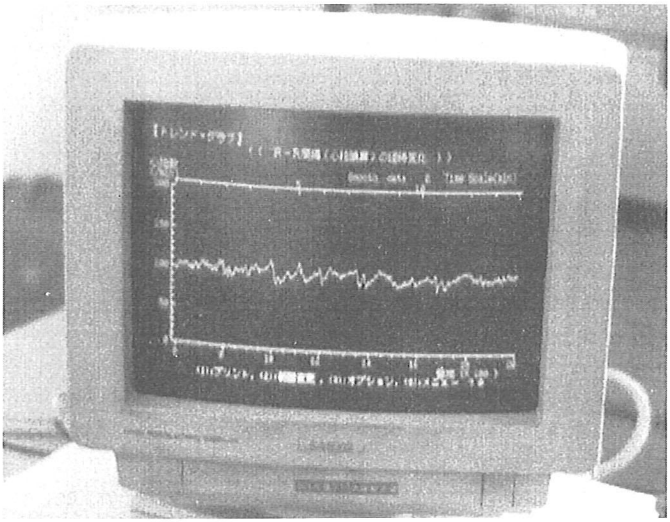

Figure 3 The heartbeat waveform display

Measurement of the level of risk perception

In this study, pedestrian subjects are selected to evaluate the safety of narrow streets. Pedestrians display physiological symptoms as well as external behavior such as keeping a safe distance away from automobiles in response to the level of risk perception. Factors such as the velocity of vehicles, spacing between road users, psychological feeling of pressure from vehicles and the type of passing such as overtaking and facing oncoming traffic cause appearance of physiological clues to the level of stress experienced by the pedestrian. Commercial vehicles such as light trucks using these roads are generally likely to be more risky for pedestrians than passenger cars and small automobiles. Therefore, the type of vehicle is adopted as an input variable. Observation techniques adopted in the determination of these characteristics are explained in the following section.

OBSERVATION

Observation technique

The field tests were carried out over a week period using twenty-one subjects. They were all males and came from the student population of the Saga University. Each subject performed two trips carrying the monitoring equipment. The pedestrian action involved walking up and down the specified street as shown in Figure 4 and their heartbeat was recorded by the monitoring device. For the purpose of comparison, the subjects were also required to walk along a protected walkway on which they would not experience any threat from automobiles.

The spacing between the pedestrians and motor vehicles has been obtained by establishing a method to record the physical location of pedestrians and vehicles. Seven short white lines were drawn on the street at 5-meter intervals and cross marks were made on these lines at 50 centimeter intervals. These marks were made using masking tape. An attempt has been made to make the marks as unobtrusive as possible, and post survey briefing has indicated that certain pedestrian subjects were unaware of the presence of these marks. Video recordings were made by three cameras placed in unnoticeable places such as behind utility poles and other suitable roadside features. Although an attempt has been made to make the observations as unobtrusively as possible, it is acknowledged that the subjects were aware that they were being monitored simply because of wires taped to their chest. As yet there is no cost-effective way to overcome this feature which may have affected the behavior of subjects.

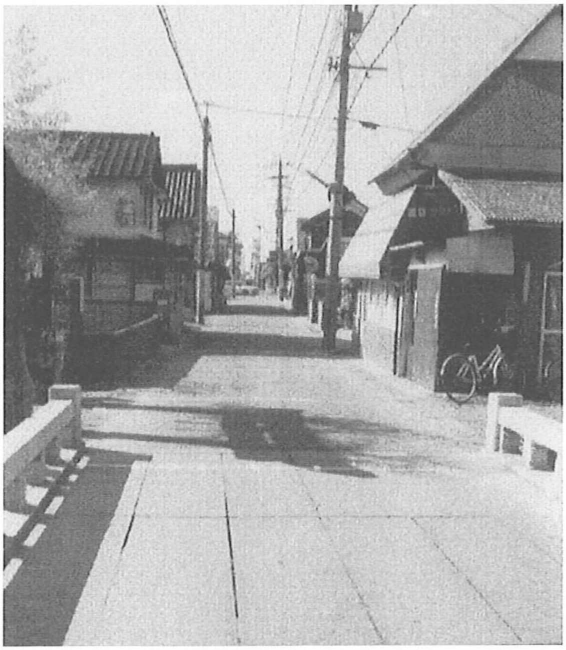

Figure 4 A narrow street under investigation

The spacing between road users in passing could be measured to the nearest 25 centimeters using these marked scales. Traffic speed was calculated based on the time taken by a vehicle to travel between two successive lines. For this purpose, time was updated on video tapes at the interval of one hundredth of a second.

Site selection

These field tests have been conducted in Saga City on clear days in November 1995. Site locations were selected from residential streets which satisfy three important criteria.

(1) Narrow streets (width less than 4.0m) have been targeted. Traffic conflicts between pedestrians and automobiles are less frequent on wide streets and are not suitable for efficient data collection.

(2) Straight streets have been selected to minimize the effects of road curvature related stresses. Road alignment is known to effect visibility levels experienced by the pedestrian and poor visibility levels act as a source of sense of risks.

(3) One-way streets have been chosen to simplify the traffic conditions experienced by the pedestrians.

Traffic volume per off-peak hour on a representative day for the average site is shown in Table 1. The amount of medium cars and bicycles were approximately equal. Light trucks comprised about 10% of the traffic stream. The speed of motor vehicles has the distribution as shown in Figure 5. More than 50% cars traveled through this narrow street with a speed of more than 30 km/hour though the speed limit was 30 km/h. This street has been considered by residents as very risky for pedestrians and cyclists. There were 71 passing movements of pedestrians by motor vehicles recorded during the observation period.

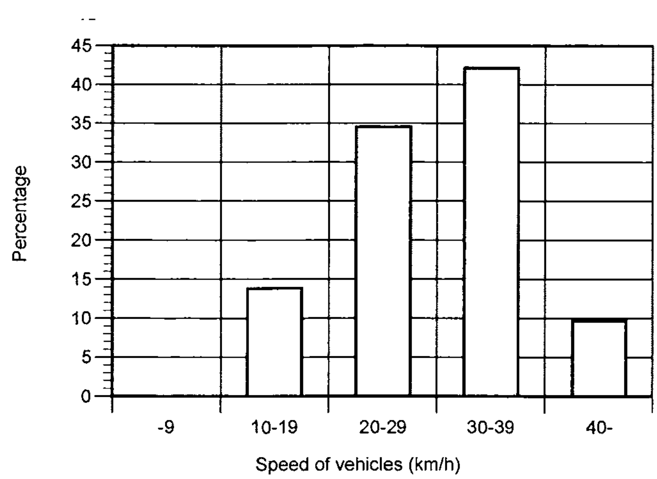

Figure 5 Distribution of vehicle speeds

Table 1 Traffic volume per off-peak hour

Type of traffic	Volume(veh/hr)
Medium car	80
Compact car	51
Light truck	15
Motorbike	26
Bicycle	91
Pedestrian	34

INCREASE OF THE RATE OF HEARTBEAT

The heartbeat of a walking person has a distinct pattern. At the commencement of the walk, the heartbeat gradually increases until it reaches an asymptote. However, the heartbeat surges when a strong external stimulation is applied in the form of a passing high speed vehicle. The research team focused on the measurement of the amount of the relative increase of pulse because of the stress stimulation compared to the stress-free walk. Figure 6 shows the fluctuations of the pulse of a representative subject. A dotted line denotes the heartbeat during the walk along the protected track. On the other hand, the solid line shows the heartbeat during the walk along the narrow street under investigation. As shown in Figure 6, the pulse rate rises sharply when an automobile is about to overtake the subject. The difference between both lines provides the relative increase of heartbeat due to the stimuli in this investigation. The strength of the fear and apprehension is estimated based on this relative difference compared to the base conditions.

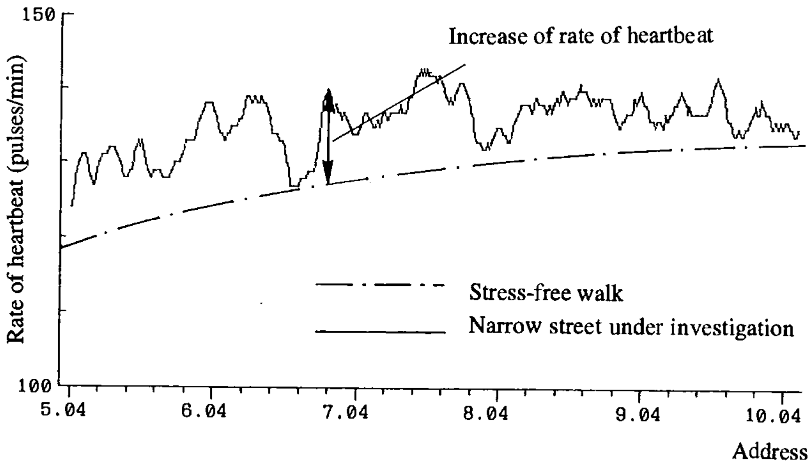

Figure 6 Fluctuations of the rate of heartbeat

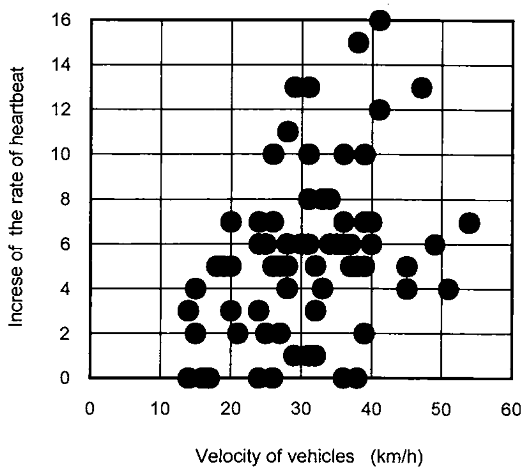

Figure 7 Increase of the rate of heartbeat and the velocity of vehicles

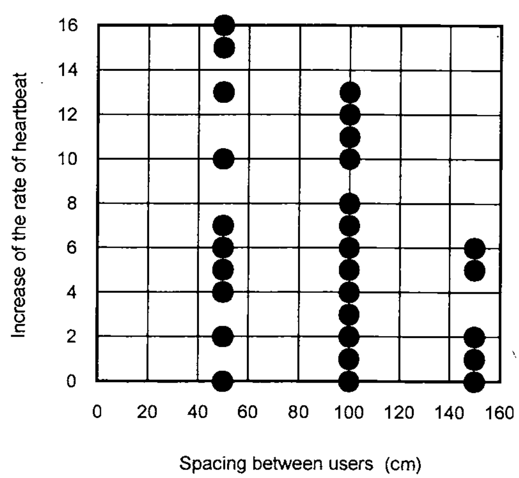

Figure 8 Increase of the rate of heartbeat and the spacing between users in passing

Increase of the rate of heartbeat and traffic conditions

Figure 7 shows the relationship between the increase of the rate of heartbeat and the velocity of vehicles. Though there is a considerable scatter in the data and shows large spread, it establishes the trend that the increase of the rate of heartbeat is proportional to the velocity of passing automobiles. It is important to note that the increase of the rate of heartbeat is relatively small for velocities below 20km/h. These passing movements at low speeds are relatively stress-free for the pedestrians. The relationship between the increase of the rate of heartbeat and the spacing between users in passing is denoted in Figure 8. As expected, the measure of stress (the increase of the rate of heartbeat) tends to decrease with the increase in spacing with the motor vehicle. There is very little stress, and therefore little change to the pulse when the observed spacing is greater than 1.5m.

Increase of the rate of heartbeat and pedestrians' behavior

Pedestrians take evasive actions such as stepping aside, reducing speed and suspending the walking action in response to the level of risk perception. These actions are selected to avoid the pedestrian getting in physical contact with passing automobiles. The larger the level of risk perception is, the clearer pedestrians' behavior and the higher the increase of the rate of heartbeat. More than 80% pedestrians have taken some actions to keep away from automobiles when the increase of the rate of heartbeat has exceeded 10 pulses per minute in this study. Consequently, for the purpose of this study, it has been decided to consider a pedestrian as feeling risk against passing automobiles when the rate of heartbeat has increased by 10 or more pulses per minute.

MODEL TO PREDICT THE LEVEL OF RISK PERCEPTION OF PEDESTRIANS

Pedestrians display external behavior such as keeping away from passing automobiles and involuntary physiological symptoms (the rate of heartbeat) in response to the level of risk perception posed by passing traffic. Previous discussion has established that the level of stress felt by pedestrian is a function of vehicle speed, spacing between users in passing, the type of passing and the type of cars. It has been also shown that if this level of risk exceeds a certain threshold, pedestrians have a relatively large increase of the rate of heartbeat, that is, feel the risk against passing automobiles. A modeling framework to incorporate such behavior is available from the discrete choice model widely used in travel behavior analysis (Ben-Akiva and Lerman, 1989). According this model, the level of perceived risk, D, and the threshold, D_0, are expressed, respectively as follows:

$$\begin{aligned} D &= \sum a_i x_i \quad \text{for} \quad i = 1,2,3,4 \\ D_0 &= b \end{aligned} \tag{1}$$

where x_i are the measurable attributes of the system considered in the behavior analysis. Parameters a_i and b are calibrated based on observed data. In this project, x_1 and x_2 denote the vehicle speed and spacing between users in passing, respectively. x_3 is a dummy variable denoting the type of passing. When the subject is overtaken by an automobile, $x_3=1$ and $x_3=0$ otherwise (facing oncoming traffic). x_4 is also a dummy variable denoting the type of car. When the vehicle is a light truck, $x_4=1$ and $x_4=0$ otherwise (medium sized cars and compact cars). Consequently, the probability that D exceeds D_0 is available from the following logit formulation.

$$P_r(D \geq D_0) = \frac{\exp(D)}{\exp(D) + \exp(D_0)} \tag{2}$$

The calibration of the model has yielded results shown in tabular form in Table 2. As the value of t statistic is founded to be extremely small, the variable denoting the type of car has been removed. The spacing between users in passing and type of passing are found to be the more important factors. Speed of the vehicle is ranked less important compared to the other two factors. The % right statistic and goodness-of-fit measure are 88.7% and 0.23, respectively. Therefore, the reproducibility of the model is deemed adequate.

Table 2 Estimation of statistical results for binary logit model

Variables name	Coefficient estimation	t statistic
Car speed (a_1)	0.0423	1.0532
Spacing between users in passing (a_2)	-0.0300	-2.3441
Type of passing (a_3)	1.7502	2.1695
Type of car (a_4)	-	-
Constant (b)	1.2799	0.6343
Sample size	71	
Number of choices	2	
ρ^2	0.23	
Choice probability (%)	88.7	

Table 3 The level of risk perception under different improvement strategies

Type of passing	Velocity of automobiles	Spacing between users in passing		
		50cm	100cm	150cm
Facing oncoming vehicle	40km/h	0.25	0.07	0.02
	30km/h	0.18	0.05	0.01
	20km/h	0.13	0.03	0.01
Vehicle overtaking from behind	40km/h	0.66	0.30	0.09
	30km/h	0.56	0.22	0.06
	20km/h	0.45	0.16	0.03

EVALUATION OF IMPROVEMENT PLAN

As mentioned above, it is possible to reduce the probability of risk that pedestrians perceive against vehicular traffic by means of reducing the maximum operating speed and widening the spacing between users in passing. These variables can be controlled by the planners. Therefore, the effect of measures that reduce the vehicle speed and widen the spacing is evaluated by using this model. The level of risk that pedestrians perceive is shown for each measure in Table 3. As shown in Table 3, the type of passing greatly influences this perceived level value. As expected, the level of perceived risk in overtaking is larger than the one in facing oncoming traffic. When the spacing between users in passing is within 50 centimeters, about 66% of pedestrians perceive risk from vehicles at speeds of 40km/h overtaking from behind. If the spacing is maintained at over 100 centimeters by means of widening of the street, the rate can be reduced by about half to approximately 30%. On the other hand, a reduction achieved by reducing the vehicle speed to 20km/h is less in magnitude as there is still 45% risk expressed by pedestrians. It is acknowledged that the reduction of vehicle speed may be justified because of other environmental reasons. Therefore, in order to reduce the level of risk perception of pedestrians, it is necessary to keep the width of the street as wide as possible. This may be possible by means of removing obstacles such as on-street parked vehicles, bicycles and vending machines.

CONCLUSIONS

The modeling framework provided here is a powerful one as it provides planners with numerical estimates as to the effect of the traffic management measures. As a general rule, it is found that street widening that results in half a meter addition to space between the pedestrian and the vehicle provides a reduction in the stress level experienced by pedestrians about twice as large as the reduction available from reducing the vehicular speed by 20 km/h. However, in space constrained planning situations, the planner has much to gain by considering implementation of strategies that lead to a speed reduction of even 10 km/h.

This paper has proposed a model to estimate the level of risk perception posed to pedestrians by passing motor vehicles. The level of risk is expressed as a function of car speed, spacing between road users in passing and the type of passing. It is acknowledged that personal attributes such as age and gender may also be important but are not incorporated into the present model because only male students were selected as pedestrian subjects in this field test. The modeling of the effects of traffic system variables (such as spacing and speed) as performed here is more useful to planners as they have better control of system variables than the personal attributes.

The type of passing is an important effect on the level of risk perception. As expected, it is seen that pedestrians consider the level of risk is much higher when they are overtaken from behind compared to being passed by oncoming vehicles. An application of the model has revealed that it is possible to quantify the effect of traffic management strategies such as road widening and speed reductions. The example presented in the paper has analyzed the effect of increasing the spacing between the pedestrian and vehicles by increment of 50 centimeters. Similarly speed reductions by decrements of 10 km/h have also been included.

The experimental technique adopted in this paper is based on the measurement of physiological symptoms of the pedestrian subjects. This involved measurement of their cardiovascular activity level by means of equipment clipped to the person in addition to other non-intrusive recording devices to monitor traffic conditions. The field tests were carried out in residential streets of Saga City, in Japan.

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