EFFECT OF UNCONTROLLED PEDESTRIAN MOVEMENT ON VEHICULAR TRAFFIC FLOW IN URBAN AREAS

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ABSTRACT

Urban traffic engineers have been dealing with the problem of safe, efficient pedestrian movements for a long time, but the possible effects of a random pedestrian behavior on vehicular flow has had relatively little attention. The purpose of this research is to determine the effects of the random pedestrian behavior on the vehicular flow in urban traffic. Different models were derived for this purpose. These models show the dependence of vehicle delays resulting from pedestrian/ vehicle friction on the pedestrian, vehicle flow, traffic density, pedestrian group size, walking speed, and the number of vehicles stopped by pedestrians.

Keywords: Transportation planning, Pedestrian movement, Uncontrolled crossing, Pedestrian survey, Pedestrian models, Vehicular delay.

INTRODUCTION

The urban traffic in Alexandria city is characterized by a random pedestrian behavior due to unsufficient pedestrian signals. Pedestrians cross the streets at random in non signal segments affecting the vehicular flow (delays), energy consumption and air pollution. The number of pedestrians and vehicles is constantly increasing, so that the pedestrian/vehicle conflict is becoming a more and more important contributor to vehicle delays. This can negatively affects the capacities of urban roads.

The complex system of pedestrian/ vehicle conflict consists of five elements: the vehicle, the driver, the road, the sidewalk, and the pedestrian. Various factors such as increasing the number of vehicles and pedestrians, high-speed vehicles and the right-of- way conflict between drivers and pedestrians are adding to the complexity of the system. This research attempted to determine the effects of the random pedestrian behavior on the vehicular flow in terms of vehicle delays by identifying some of relevant variables that may affect both the pedestrians and the vehicular flow. The variables selected are quantitatively factors for which the data is relatively easy to collect. These factors were used to form a transportation model among variables.

RELEVANT VARIABLES

One of the first and most important considerations for developing a transportation model, in this context, is the identification of significant variables that affect pedestrian/vehicle friction. Factors affecting vehicular flow are broken into four general categories:

* Physical and operating conditions,
* Environmental conditions,
* Traffic characteristics, and
* Control measures

The pedestrian is a physical element of the traffic system and must be given the same consideration as any other factor of the physical and operating conditions. The pedestrian reactions at the curb must be considered along with all other environmental factors for the vehicular flow. Statistically, it was found that the volume of traffic affects the pedestrian crossing decision [1,4]. Group crossing speeds were found to be slower than individual crossing speeds and groups of pedestrians accepted shorter gaps than individual pedestrians.

Some traffic characteristics of the vehicular flow must also be given serious consideration by pedestrian/vehicle friction. It was found that the acceptable gap or degree of chance that a pedestrian is willing to take for crossing a road is function of [2,9]:

- o Speed of operating vehicles,
- o Average number of waiting pedestrians,
- o Average delay of waiting pedestrians,
- o Characteristic of pedestrian behavior,
- o Environmental conditions, and
- o Width of a roadway to be crossed

The control measures are probably the most important factors considering pedestrian/vehicle friction. It was found that crosswalks of the pedestrian crossing (zebra) can reduce the vehicular delays and give a much more efficient operation[9].

The following variables were considered to have possible effects on the vehicular flow where the pedestrian/vehicle conflict occurs:

- o Vehicle flow (f_v),
- o Pedestrian flow (f_p),
- o Traffic density (T_d),
- o Pedestrian walking speed (v_p) and street width (d_s) which determine the duration of crossing a street (T),
- o Number of pedestrians involved (n_p),
- o Number of vehicle involved (n_v),
- o Parking conditions, and
- o Location.

DATA COLLECTION

According to observations, Locations to be studied were carefully selected to be representative of a typical pedestrian/ vehicle friction sites. Two sites were surveyed: One in Horiya street (SITE1: Sidi Gaber), which is a high-volume traffic arterial in Alexandria city, and the other in city center Manshiya (SITE2), which is an important part of central area.

The data collection phase of this research was conducted by three persons at the various locations on Horiya street and Manshiya city center. Observations were made between vehicle flow per minute, f_v, pedestrian flow per minute, f_p, traffic density, T_d, number of pedestrians involved, n_p, and the number of vehicles involved n_v. Duration of crossing the street by each group of pedestrians [1-2 persons per group, 2-5 persons per group, and more than 5 persons per group] in non signalized segments were also observed. This consists of average walking time for pedestrian, t_w, and clearance time for vehicles t_c. Separate observations were made for t_w, and t_c for the different pedestrians group sizes.

Data was collected for all variables simultaneously from 8 A.M to 3 P.M and from 5 P.M to 11 P.M on Tuesdays, Thursdays, and Fridays, during the weeks of May 7 to June 26, 1994. These periods were chosen because a preliminary field observation showed that pedestrian movements and vehicle traffic flow were both high during this time giving a high potential for pedestrian/vehicle conflict. Table (1) shows a sample of the data collected.

DATA ANALYSIS

Observations of pedestrians behavior at uncontrolled crossings in Alexandria city showed that, on arriving, the pedestrian crosses immediately or waits until a gap in the traffic stream equal to or greater than the critical gap is offered. If, however, he finds other pedestrians waiting on arrival or is subsequently joined by other pedestrians during his waiting period, then each of the waiting pedestrians assumes the shortest critical acceptance gap associated with the group so that all cross together once a suitable gap is presented.

The gap acceptance behavior of the pedestrians in general can be formally represented by a gap acceptance function for the pedestrians, defined to be the probability that a pedestrian or pedestrian group accepts a given gap size in the vehicular flow.

Table 1. Sample of data collected.
Pedestrian random behavior survey

Site:
Date:
Day:

Time	f_v veh./min	f_p Ped./min	Pedestrian group size 1-2	2-5	> 5	T (sec.)	n_v (vehicle)
11.00-11.15	59	60	+			15	9
				+		20	18
					+	23	21
11.15-11.30	47	65			+	22	20

Table 2. Model constants related to pedestrian crossing group.

Model Constants	City center model f_v=45 veh./min, T_d=50 veh./km			Urban Traffic Model f_v=55 veh./min., T_d=60 veh./km		
	Group 1-2	Group 2-5	Group > 5	Group 1-2	Group 2-5	Group >5
a	6.4038	6.9155	7.6450	8.4339	9.123	9.9644
b	1.4406	1.1975	0.7673	1.1915	1.224	1.3345
c	0.3085	0.3484	0.3409	0.3175	0.3181	0.3253
d	0.6813	0.8079	0.9624	0.7371	0.8221	0.84256
R	0.85*,0.81*	0.88, 0.77	0.76, 0.79	0.82, 0.81	0.82, 0.84	0.88, 0.82

* Regression coefficient for model 2, and model 3

The idealized assumption of consistent behavior, i.e. of a fixed critical gap for a pedestrian or a pedestrian group, can be expressed as the simplest case of a gap acceptance function given by:

$$p(t) = \begin{cases} 0 & t < C \\ 1 & t > C \end{cases} \quad \text{.... (1)}$$

where:

p(t): probability that a pedestrian or a pedestrian group accepts a gap of size t seconds,

C: pedestrians or pedestrian group critical gap, which can vary over the number of pedestrians.

Equation (1) is a "step" function, shown in Figure (1) and according to this criterion a pedestrian or a pedestrian group accepts 100% of gaps greater than C seconds and 0% of gaps less than C seconds.

For t > C, the period in which a pedestrian or a pedestrian group is walking across the urban road is a loss to vehicular traffic, as the vehicles are expected to wait until all pedestrians have crossed the road. Therefore, it is supposed to be related to vehicular delays.

If pedestrian delays are not more than a certain limit, pedestrians prefer to wait for an opportunity to cross at grade, joined together in a group, accepting critical gaps, and crossing the road, rather than devote extra time (and energy) to crossing by means of a pedestrian subway or a foot-bridge.

Average pedestrian delays for a given traffic volume decrease with increasing pedestrian volume, while average vehicular delays for a given traffic volume increases with increasing pedestrian volume.

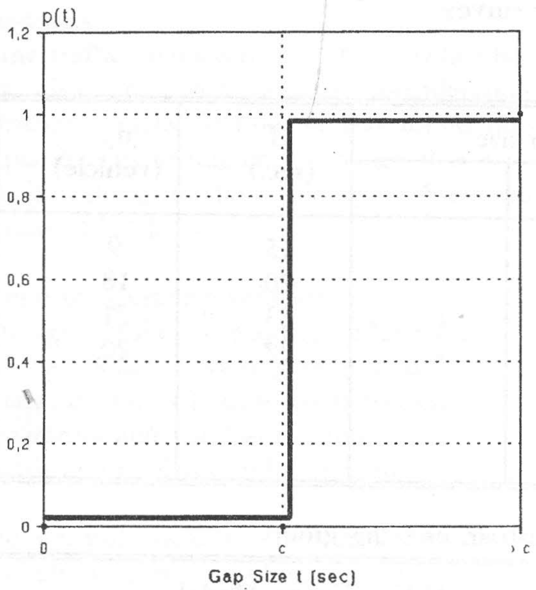


Figure 1. Pedestrian's gap acceptance function.

Further results from data analysis show that younger pedestrians accept shorter gaps in the vehicular flow.

MODEL FORMULATION

After the relevant variables had been identified and the data for these variables had been collected, a statistical method, "the multiple - regression technique", was used to formulate a model that would describe the effects of the random pedestrian behavior in Alexandria city on the vehicular flow.

For a certain vehicular flow, pedestrian flow and traffic density, four models were developed in this research to determine the effect of pedestrian random behavior on vehicular flow. Model 1 determines the duration of crossing a street related to average free walking time, for the subject lane group, and number of pedestrians involved. Model 2 determines the number of vehicles per minute affected by pedestrians friction as a function in the duration of crossing a street. Model 3 determines the loss of time to vehicular traffic per vehicle and minute at a place where pedestrians cross randomly, as a function in the number of vehicles involved.

These models were derived for two cases; city center model with a vehicular flow of 45 veh./min, pedestrian flow of 60 ped./min, and traffic density of 50 veh./km, and urban traffic model with a vehicle flow of 55 veh./min, pedestrian flow of 60 ped./min, and traffic density of 60 veh./km. Each case was divided into three sub-cases according to pedestrian group size; 1-2, 2-5, and > 5 persons per group. Table (2) illustrates the model constants related to pedestrians group size, vehicular flow, and traffic density.

Models derived were:

City center model (f_v = 45 veh./min, T_d=50 veh/km, f_p=60 ped./min):

Model 1:

$$T = t_w * n_p^{(0.5434)}$$

Regression coefficient, R = 0.9686

Model 2:

$$n_v = a * T^{(c)}$$

Model 3:

$$D = b * n_v^{(d)}$$

Urban traffic model (f_v = 55 veh./min, T_d=60 veh./km, f_p=60 ped./min):

Model 1:

$$T = t_w * n_p^{(0.7075)}$$

R = 0.914

Model 2:

$$n_v = a * T^{(c)}$$

Model 3:

$$D = b * n_v^{(d)}$$

MODEL EVALUATION

The variables f_v, f_p, n_p, T_d, vehicle flow, pedestrian flow, pedestrians involved, and traffic density, appear in the first model. The greater the vehicular flow and density, and pedestrian volume, the greater is the duration of conflict time between them. Figure (2) shows the relationship between duration of crossing a street, number of pedestrians involved, vehicular flow and traffic density.

The number of vehicles involved in the delay (n_v) resulting from pedestrian/ vehicle friction is obviously an important factor in the vehicle delay value. The greater the duration of crossing a street (conflict time) the greater is the number of vehicles involved, and the greater is the delay time. Figure (3) and Figure (4) illustrate the relationships between conflict time, number of vehicles affected by pedestrian friction and delay time for various vehicular flow and density.

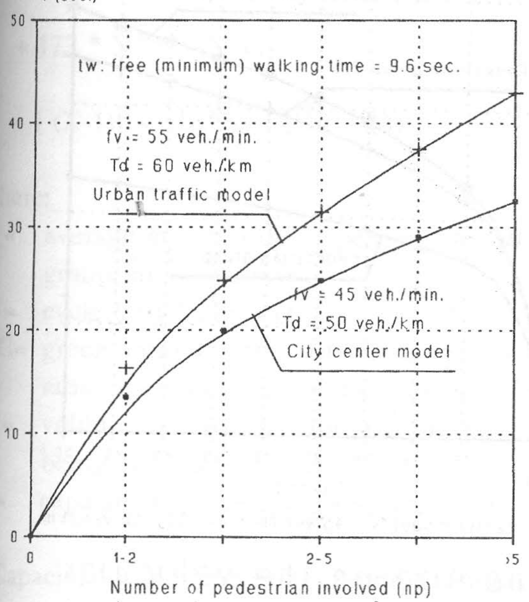


Figure 2. Relationship between duration of crossing a street randomly, number of pedestrians involved, vehicular flow and traffic density.

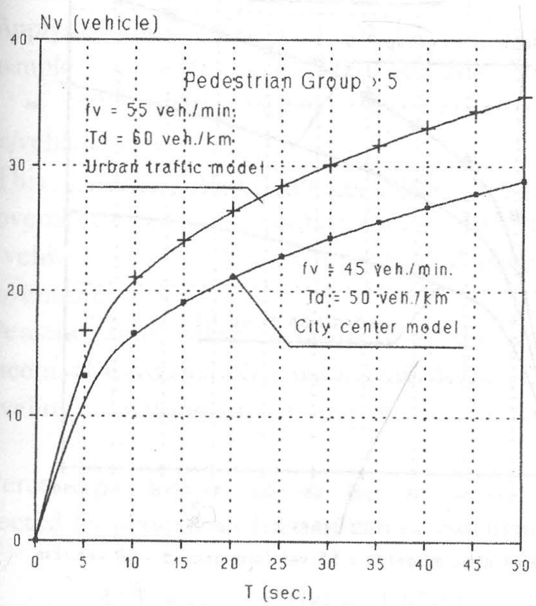


Figure 3. Number of vehicle affected by pedestrian friction related to conflict time, vehicular flow and traffic density.

As shown in Figure (4), vehicular delays resulting from pedestrian/vehicle friction decrease as traffic densities decrease.

The pedestrian group size appears in each model. This is a case where increased exposure or probability of a conflict occurs with the increased pedestrian group size crossing randomly a street. Generally, vehicular delay increases as the pedestrian group size increases. Studies [1,3] have also shown that a pedestrian in a group will take a greater risk than an individual pedestrian waiting on the curb. An increase in pedestrian volume gives a greater probability that a group situation exists. Figure (5) shows the effect of pedestrian group size on the vehicular delay for a certain vehicle flow.

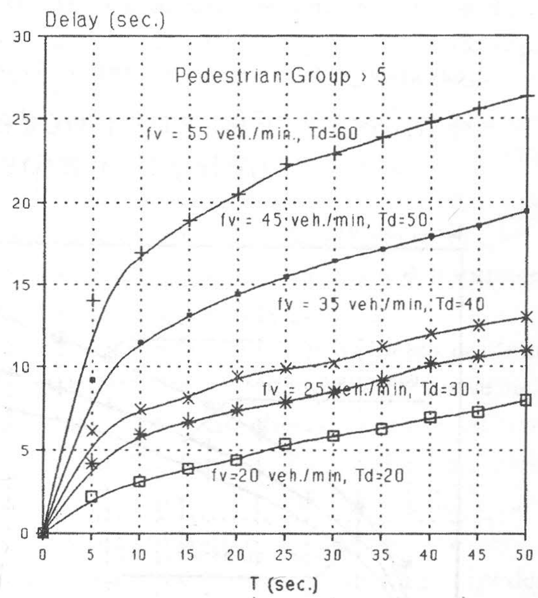
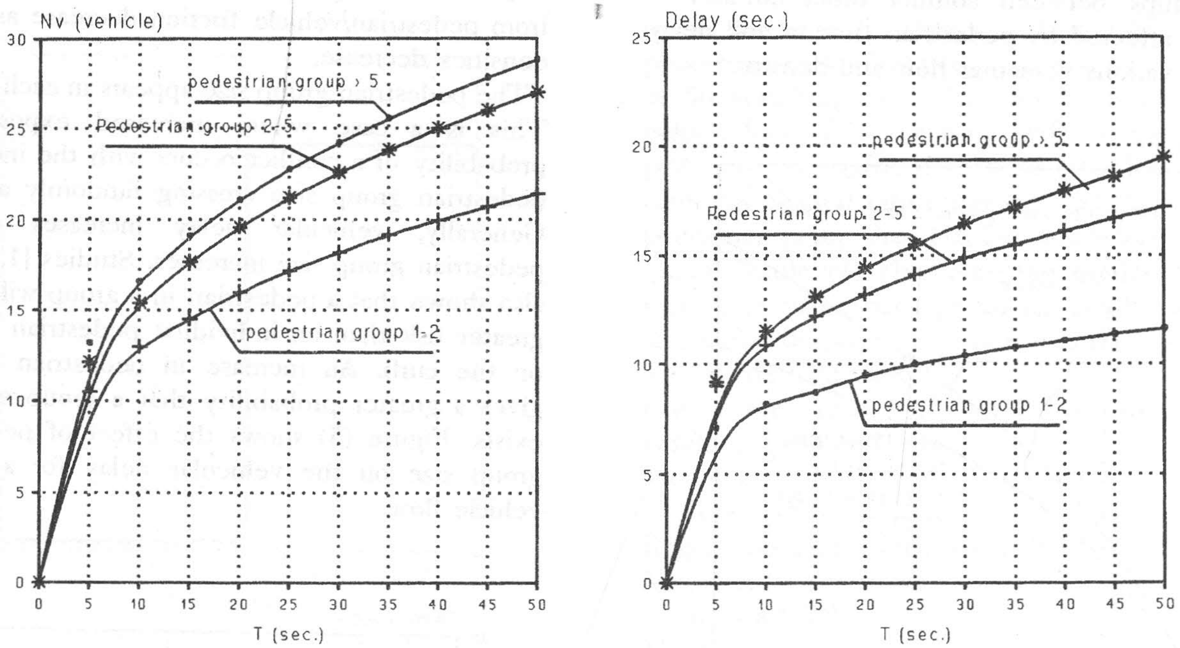


Figure 4. Delays of vehicle related to duration of crossing a street, vehicle flow, and traffic density.

MODEL APPLICATION

An example: let us consider that tw=14.5 sec for a 3-lanes road, f_v=55 veh./min, f_p = 60 ped./min, and T_d=60 veh./km for urban traffic, and pedestrian groups of ">5 persons" crossing a street. Applying model (1), (2), and (3):

T=45 sec., n_v=34 veh., and D=26 sec/vehicle/min.



City center model fv = 45 veh./min and Td = 50 veh./km

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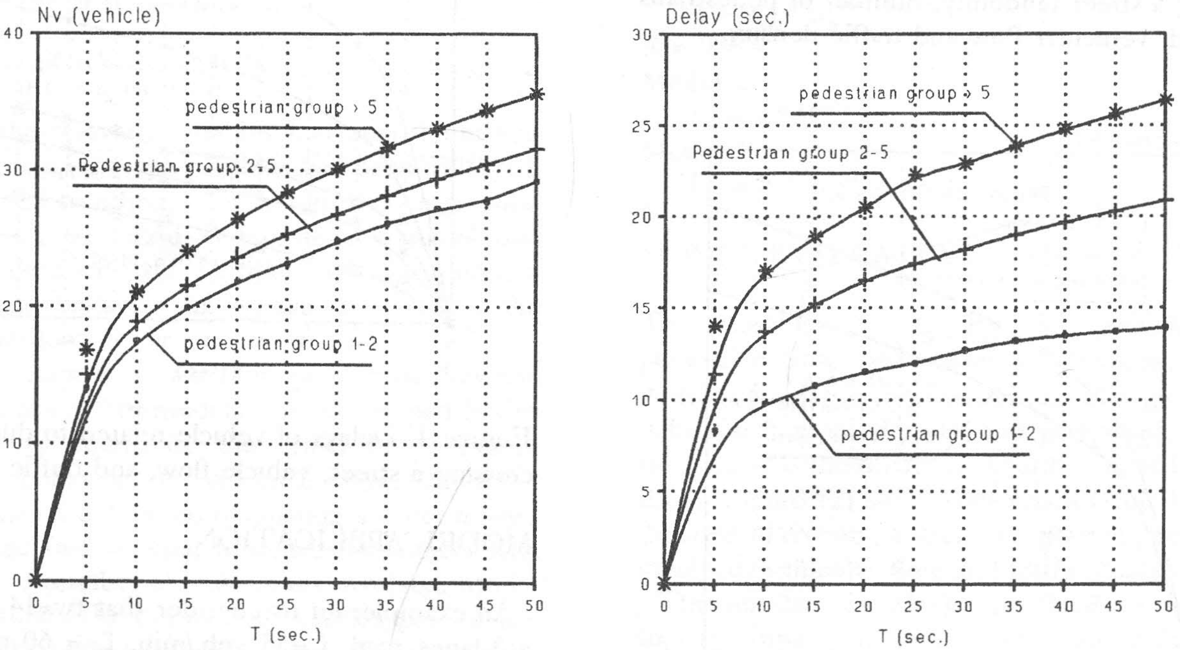
Figure 5: Effect of pedestrian group size on the vehicular delays in a pedestrian/vehicle friction



Urban traffic model fv = 55 veh./min and Td = 60 veh./km

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This means that a vehicular flow of 55 veh./min and traffic density of 60 veh./km, for a 3-lane road, will suffer a delay of 26 sec/vehicle/min, as pedestrian groups of ">5 persons", with a pedestrian flow of 60 ped./min, cross a street with free walking time of 14.5 sec.

By using a pedestrian signal, vehicular delays can be calculated as [3]:

$$d = 0.38 * C * [1-g/C]^2/[1-(g/c)*(X)]$$

$$+ 173 * X^2 * \{ (X-1)$$

$$+ [(X-1)^2 + (16*X/c)]^{1/2}\} ....(4)$$

where:

d = average stopped delay per vehicle for a lane group, in sec/vehicle;

C = cycle length, in sec;

g/C= green ratio for the subject lane group; the ratio of effective green time to cycle length;

X = volume-to-capacity ratio for the lane group being considered; and

c = capacity for the lane group (vph).

Capacity for the lane group being considered can be calculated as:

$$c = 1{,}600 * N * (g/C) \qquad (5)$$

where:

N = number of lanes in the lane group.

Applying model (4), and (5) on the previous example, for C=90 sec, g/C=0.6, and X = 0.9 : d = 15 sec/vehicle/90 sec cycle, d=10 sec/vehicle/min cycle.

This means that uncontrolled pedestrian movement causes more delays (nearly three times) to vehicular traffic flow than controlled pedestrian movement.

Percent time delay is defined as the average percent of time that all vehicles are delayed while traveling in platoons due to the inability to pass[3].

Percentage loss of time to vehicular traffic affected by pedestrian friction can be calculated as:

$$D\% = (D/60)*100 = 1.67 D \qquad (6)$$

Obviously there may be a considerable amount of delay to vehicles at pedestrian crossings. It is therefore considered necessary that warrants for a type of crossing (no special treatment, signal-controlled and uncontrolled pedestrian crossings) may be based on acceptable delay to vehicle. Each community or city may stipulate an acceptable delay to vehicles depending on the traffic circumstances and the relative cost of delay between a vehicle and a pedestrian.

Permissible values of D%, as a limit for constructing a subway or footbridge, and for introducing a signal-controlled pedestrian crossing, must be determined for the traffic circumstances in Alexandria city.

According to Pillai [6], application for a developing country, if the observed flow conditions are such that they give rise to the value of percentage loss of time greater than 40%, then it may be necessary to provide a grade-separated crossing (either a footbridge or a subway).

A permissible value of 40% delay, as a limit for constructing a subway or footbridge, and 20% for a signal-controlled pedestrian crossing, may be accepted for the traffic circumstances in Alexandria city centers. These values can be minimized for the urban traffic in Alexandria city.

As the acceptable delay to vehicles is identified, it is possible to determine warrants for vehicle and pedestrian flows to choose a type of crossing suitable for the locality and traffic characteristics. The different types can be "no special treatment" zone, signal-controlled pedestrian crossing, and uncontrolled pedestrian crossing (pedestrian subway or footbridge).

"No special treatment" zone: This is a site where no conflict exists between a vehicle and a pedestrian.

Signal-controlled and uncontrolled pedestrian crossings (subway, footbridge): If the percentage loss of time (D%) is greater than 20% and less than 40%, then there is a need for a signal-controlled pedestrian crossing. For a percentage > 40%, it is suggested that the need for a subway or footbridge is a must. Figure (6) shows warrants for the type of crossing.

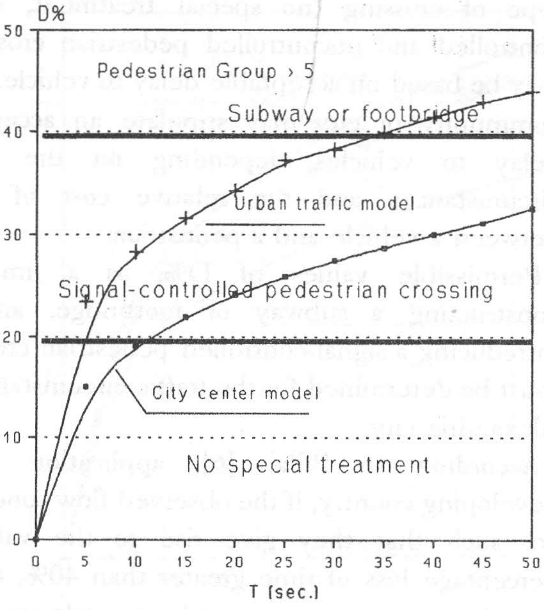

Figure 6. Warrants for the type of crossing.

CONCLUSIONS

This research was initiated to determine the effects of the pedestrian random behavior on the vehicular flow. Significant models were proved. These models show the dependence of vehicle delays resulting from pedestrian/vehicle friction on the pedestrian, and vehicle flow, traffic density, pedestrian group size, walking speed, and number of vehicles that were stopped by pedestrians.

Pedestrian random behavior causes more delays (nearly three times) to vehicular traffic flow than controlled pedestrian movement.

To minimize vehicle delays resulting from pedestrian/vehicle friction, type of crossing suitable for the locality must be chosen. An acceptable delay to vehicles depending on the traffic circumstances and the relative cost of delay between a vehicle and a pedestrian must be determined. As the acceptable delay to vehicles is identified, it is possible to determine warrants for vehicle and pedestrian flows to choose the type of crossing. This type of warrant is based purely on field conditions.

A successful pedestrian scheme might be either one of the following, or a combination of any of the measures outlined below:

* Introduction of zebra crossings;
* The introduction of signal-controlled pedestrian crossing;
* The construction of subways or foot-bridges,and
* The conversion of carriageway to pedestrian streets when essential traffic has been diverted elsewhere.

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