A Knowledge-based System for Pedestrian's Roadway Crossing Behavior through Video Cameras

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ABSTRACT

An attempt was made to investigate behavioral responses for pedestrian crossing roadways using a normal-based camera setup and a Personal Computer (PC)-based vision system along with an expert system developed specifically to help non-experienced people to perform a safe roadway crossing. This process was demonstrated by studying conflicts between pedestrians and vehicles as an indicator for a pedestrian crash. Two normal-based cameras were used to film pedestrian-traffic movements. A vision system was used to extract about 3317 conflict observations through digital images at six different locations in Irbid-City, Jordan. A database of pedestrian, traffic and geometric related information was developed. The collected variables in this database included: pedestrian's speed, vehicle's speed, vehicle distance, type of vehicle, geometry of the road, land use, location of conflict, pedestrian facility, pedestrian distance from the crossing location, age of pedestrian, gender of pedestrian and angle of crossing. Statistical regressions were carried out to establish useful models to estimate pedestrian's speed from the mentioned variables. An expert system with the basic If... Then forward and backward chaining of the knowledge-based rules along with decision trees was developed using the VP-Expert Shell in order to help non-experienced pedestrians in making safe decisions to perform roadway crossing. The system was validated and checked with actual data of pedestrians crossing in different locations for both: safe crossing and not crossing cases. Results of this investigation indicated that: 1) The linear multiple regression model was the most significant model to predict the relationship between pedestrian's speed and the developed database variables; 2) Vehicle's speed, gender of pedestrian, distance between vehicles, geometry of the road, land use and location of the road, and pedestrian's facility variables were found to be the most significant contributors to pedestrian behavior while crossing the road; 3) Normal-base camera setup has proven to be a useful, practical and accurate camera configuration and data acquisition system for pedestrian and traffic studies; 4) Conflicts between vehicles and pedestrians can be used as an indicator for pedestrian crashes; and 5) Expert systems have proven to be useful educational systems to assist non-experienced pedestrians to perform decisions regarding safe roadway crossing.

Keywords: Pedestrian-Vehicle Conflict, Computer Vision, Knowledge-based Systems, Expert Systems, Traffic Crashes, Statistical Models.

INTRODUCTION

A growing awareness of the nature and extent of the pedestrians' safety problem has likely led to great research and development by traffic engineers. Each year there are a lot of crash victims. For example, pedestrian traffic crashes in Irbid-city, Jordan, with a population of about 350,000, resulted in 899 victims in 1995; i.e. 866

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injuries and 33 fatalities (Jordan Ministry of Interior, Public Security Department, 1995).

The suffering loss of human life caused by these crashes is a serious national problem (Snyder, 1972). Pedestrians' movements have become increasingly difficult as a consequence of the construction of wide roads with heavy traffic flows. Studies showed that pedestrians' crashes are correlated to many pedestrian behavioral factors and road geometrical factors (Dernellis and Ashworth, 1994). These factors include: 1) Pedestrian risk by age and gender; 2) Land use (zone type); 3) Traffic volume and speed; 4) Crossing angles; 5) Geometry of the road; and 6) Type of vehicle.

Studies showed that the risk taken by men is greater than that for women, and that children are in a higher risk than that for aged pedestrians (Grayson, 1987; Al-Masaeid *et al.*, 1996). As street patterns (activities as work zones, schools,… etc.) increase, the risk in road crossing increases (Hocherman and Zaidel, 1987; McCoy and Heimann, 1990; Russell and Hine, 1996). As traffic volume and speed increase, road crossing difficulties rise (Pasanen and Salmivaara, 1993). For example, Katamine and Al-Salman (1995) found a direct relationship between traffic flow and average crossing speed. Difficulty in crossing the road leads pedestrians to cross at steeper angles. This will indeed result in a longer time for the cross, which complicates the crossing action and increases the pedestrians' exposure to traffic. When pedestrians cross with steeper angles, they may be far from the vehicle or close to it so that the vehicle tries to stop or to reduce its speed as a reaction for pedestrians' movement. Geometric road elements; such as median width, road width and sidewalk influence the behavior of the pedestrians. Increasing the road width leads to more crossing difficulties for pedestrians (Al-Masaeid *et al.*, 1993).

Conventional (manual) methods used to measure pedestrian-traffic conflicts have a major drawback of time, cost, labor and accuracy. Whereas, video-based data acquisition systems show a great potential to improve data collection. They can yield real-time measurements, reduce labor and enhance accuracy (Reading *et al.*, 1995).

Development of knowledge-based systems, along with image-based data acquisition systems, is anticipated to help in establishing a national system for traffic regulations. These systems are expected to help teaching pedestrians how to cross roads with high safety potential, without the need for experts.

The presented research work herein studied the pedestrians' behavior while crossing the road using the conflict between traffic and pedestrians as a risk response factor. Different factors affecting this behavior, including road geometry; traffic volume and speed; pedestrian's speed, gender and age; and land use, were also investigated using Charge-Coupled-Device (CCD) camcorders as data acquisition system. A knowledge-based system for pedestrians' road crossing was developed. Moreover, statistical models for pedestrian and traffic speeds were developed as functions of variables affecting pedestrians' behavior while performing road crossings. Sample locations were utilized in the study including signalized and unsignalized intersections, mid-block and school-zone crossings.

LITERATURE REVIEW

The incidence of pedestrian-vehicle crashes in Jordan as a developing country is alarming and pedestrian safety deserves nationwide attention. Studies showed that five out of six injuries and two out of three deaths occur to pedestrians in urban areas (Choueiri *et al.*, 1993). Of people struck by passenger cars, 31 per 1000 were killed. Among all categories of people injured by motor vehicles, pedestrians have the highest ratio of deaths to injuries. In fact, the reported injuries for pedestrians are almost double that for motor vehicle occupants. The severity of a pedestrian crash depends to a greater extent on the collision speed of the vehicle, especially in the range of the speeds usual in urban traffic (Pasanen and Salmivaara, 1993). It seems that at least 80% of the crashes occurred at intersections located in predominantly commercial surroundings, where pedestrians and vehicles are both in large numbers.

Pedestrian movements in central urban areas have become increasingly difficult as a consequence of the construction of wide roads with heavy traffic flows. A pedestrian conflict situation potentially occurs when a pedestrian crosses in front of a vehicle that is moving along the road.

As reported in a United Nations document; UNECA in 1994 (Abbas *et al.*, 1996), the risk of having a crash is a direct consequence of several factors and elements such as: 1) behavior of pedestrians; 2) behavior of drivers; 3) road environment (surface condition, geometric alignment, speed limits, …etc.); 4) pedestrian environment (sidewalk, crossing facilities, crosswalk, …etc.); 5) vehicle condition and type; 6) the amount of traffic enforcement; and 7) traffic exposure. Pedestrian's behavior while crossing a road depends on the pedestrian's gender, age and level of education, in addition to land use, geometric design and vehicle's speed (Aoki and Moore, 1996).

The geometric design can be an effective method for increasing vehicular and pedestrian safety and capacity. Medians are considered to be beneficial to pedestrian safety and operation. The existence of sidewalks and marked crosswalks can also help in providing safer crossing for pedestrians. On the other hand, if the number of lanes increases, the risk continues to be higher since the crossing distance for the pedestrian will increase (Al-Masaeid *et al.*, 1993; Al-Masaeid *et al.*, 1996).

Studies show that every year at least 80% of the crashes that occurred at intersections were predominantly located in commercial surroundings, while only 10% of the crashes occurred in the neighborhood of university areas (Al-Masaeid *et al.*, 1996).

Safety depends to a high degree on vehicular speed. The severity of pedestrian crash depends to a great extent on the collision speed of the car. Bowman and Vecello (1992) studied pedestrian walking speeds and the conflicts at urban median locations. The study included analysis of urban and suburban medians located on unlimited-access arterials. Pedestrian walking times were measured on: raised median, two-way left turn and undivided roads. Walking speeds were computed for three age categories of pedestrians. Statistical tests were applied to determine the effect of median type, crossing location and pedestrian age on walking speed. They were also applied to determine the effect of crossing location, median type and crash rate on conflict type. The results indicated that pedestrian walking speeds depend on the age of pedestrian and his/her crossing location. The type of median (raised or marked) did not affect pedestrian-vehicle conflicts.

One of the primary variables in pedestrian characteristics is the walking speed. There is considerable variation in the walking speed of pedestrians depending upon their age and trip purpose.

The Manual on Uniform Traffic Control Devices (MUTCD) indicated that the normal walking speed could be assumed to be 1.2 m/sec (4 ft/sec) (Al-Masaeid *et al.* 1993). Other studies, however, indicate that if a walking speed of 1.2 m/ sec is used to determine the pedestrian clearance interval, 50 % of pedestrians will have to walk faster than their normal walking speed to cross safely within the allocated green time. Geometric design and vehicle movement paths complicate problems at signalized intersections.

A pedestrian conflict situation occurs when a pedestrian crosses in front of a vehicle, thus creating a potential collision situation. The vehicle brakes or swerves, then continues through the intersection. Any such crossing on the near side of the intersection is considered to be a conflict situation (Bowman *et al.*, 1995).

Average pedestrian delay in crossing is usually measured at specific crossing points, such as junctions. Delay gives no indications of the extent to which pedestrians make no attempt to cross or when they look, perhaps hesitate and move on rather than attempt to cross in response to traffic conditions.

CAMERA SETUP

An off-the-shelf digital data acquisition vision system, which was available at the Surveying and Photogrammetry Laboratory of the Civil Engineering Department, at Jordan University of Science and Technology (JUST), was used to capture images and to find image coordinates in this research work. CCD cameras using 8-mm tape, with the optical axis perpendicular to the mapped object (normal case photography), were used to map vehicles and pedestrians conflicts at the crossing. The cameras were equipped with a zoom lens capability ranging from 8.5 mm to 75 mm. The origin of photograph system lies at the perspective center and the plane of the photograph is representing the (x,y) plane, z being a constant. The perspective center of the lens lies on the optical axis. Its distance, along the z-axis, from the plane of the photograph is the focal length (*f*). The optical axis of the camera lens is oriented to be normal (perpendicular) to the plane of the photograph at the principal point. This represents a relatively simple reduction technique because it computes the ground point 3-D coordinates of X and Z-axes independently of the focal length.

CCD cameras were used because of their real-time potential, ease-of-use and low-cost (Obaidat *et al.*, 1997; Obaidat *et al.*, 2005). Each camera was placed on a stand where the optical line is perfectly perpendicular to the vehicle movement or the pedestrian crossing to obtain a uniform scale for each image. A sufficient field-of-view was selected for each camera in each location. For the pedestrian camera, it was sufficient to see a field of view showing the road width, which was at most two lanes. For the traffic camera, however, at least 30 meters road length should be seen in the field of view of the camera in order to give representative speed profiles of the traffic.

The zoom capability of the lens was fixed to 8.5 mm focal length with variable camera distances for each location depending on the obstacles in the camera field-of-view. This produced different scales for different locations for both traffic and pedestrian images. The images were captured at sun light effect and no special lighting facility was used.

The two cameras were used in the field to collect data for the two perpendicular movements: the traffic movement and the pedestrian road crossing. They will be called: the pedestrian camera and the traffic camera. The time was common for both movements to correlate the effect of each movement on the other. Figure (1) shows the locations of the two CCD cameras: the traffic and pedestrian cameras and their field-of-views for a mapped scene.

IMAGE-SCALE

A linear object of measured length at the middle of the field-of-view was selected for scaling purposes. The location of that linear object was near the principal point to assure elimination of image radial and decentering distortions. Examples of the measured linear objects included: median opening, windows, gate-width, road-width, …etc.

The length of the linear object on the image domain was also measured in pixels. Thus, a scale conversion can be made to measure any required length in the image and to convert it into actual measurements. Image lengths were measured based on image coordinates. The x-coordinates were along the rows and the y-coordinates were along the columns. Due to the usage of normal-based photography, the x-coordinates were only required for the pedestrian and traffic measurements for each camera.

CONFLICTS BETWEEN VEHICLES AND PEDESTRIANS

Conflicts between vehicles and pedestrians were used as a response factor for potential crash. A conflict was defined as the effect of vehicle’s movement on the pedestrian’s movement. Speed profiles of both pedestrians and vehicles will show that the traffic movement and speed of vehicles affect the behavior of pedestrians.

To visualize a conflict between vehicles and pedestrians, there is no definite or objective measure; i.e. it is a qualitative response. However, a subjective criterion could be used to define the occurrence of conflict by visualizing the behavior of the pedestrian. If the pedestrian changes his or her speed due to the existence of vehicle moving along the road, he or she might be affected due to traffic in order to avoid crash occurrence. Other indicators that might be used for conflict prediction include: changing the crossing angle, making a backward movement, changing the pedestrian speed and changing the vehicle speed. Playback mode of tapes was used to observe conflicts between pedestrians and vehicles. Therefore, not all moving vehicles along the road were considered with a potential conflict with pedestrians unless they really had an effect on pedestrian movement.

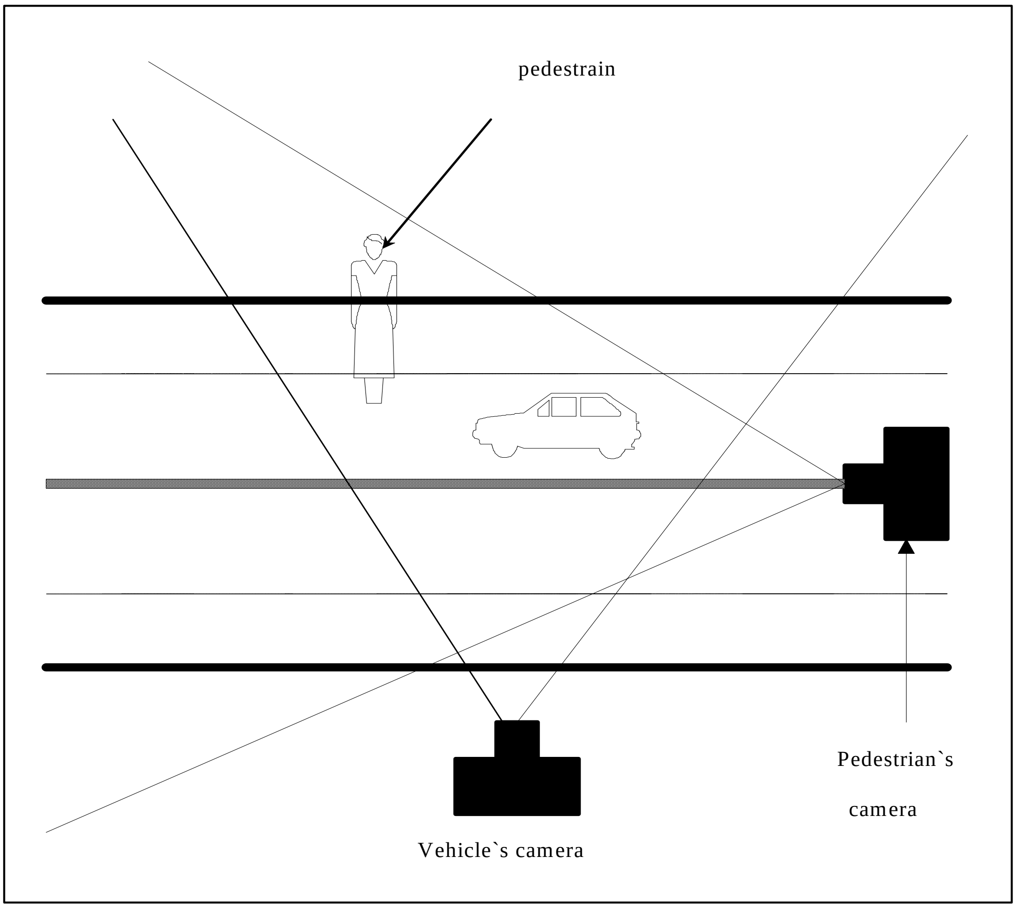

Figure 1: Locations of the traffic and pedestrian cameras and their field-of-views.

CONFLICTS AND CRASHES RELATIONSHIP

Since it is extremely rare to capture pedestrian crashes on film, conflicts between vehicles and pedestrians were used as a response factor for the crashes, because potential conflict may lead to a crash. To prove the validity of this assumption, crash data sets for the studied locations were obtained from the police department in Irbid, Jordan. Crash diagrams drawn on the police crash forms were used after the police assured that the crash locations matched the studied conflict locations. A policeman from the traffic patrol department was taken to the studied locations to assure the exact locations of the crashes. The data for each crash included the following information: time and date of crash, age and gender of pedestrian, and type of vehicle.

Number of conflicts at each location was counted using the PC-based computer vision system. A scatter plot for the crashes and the conflicts was drawn. The scatter plot shows a linear relationship between these two parameters. As the number of conflicts increased, the number of crashes increased. A linear regression model was carried out to represent this relationship according to the following equation:

$$A = 5.19\ C + 11.4 \qquad (R^2 = 0.9) \qquad (1)$$

where;
A = Number of pedestrian crashes/ year;
C = Number of conflicts/hour.

Thus, the number of conflicts could be used as a measure for the number of crashes using the number of verified assumptions, including; 1) study time, which was selected during peak-hour time, and crashes which historically occurred at the same peak- hour time; 2) the daily peak-hour volumes across several week days for the same location were almost the same; and 3) the majority of pedestrians' crashes occurred within peak-hour time. Therefore, film recording was made during weekdays at times that match days of crashes that appeared in the police crash reports.

Table 1: Descriptive Statistics for the Studied Locations.

Location Number	Description	Road Type	Cross Walk Existence	Side Walk Existence	Land Use	Traffic Volume	Speed Limit (km/hr)
1	-Mid-block -Arterial Road -In front of school	4-lane diveded with median	Yes	Both sides	Residential	Heavy	50
2	-Mid-block -Arterial Road	4-lane diveded with median	No	Both sides	Commertial	Heavy	50
3	-Unsignalized intersection -Next to bus station	4-lane diveded with median	No	No	Commertial	Heavy	40
4	-Signalized intersection -3 phases -Next to bus station	4-lane diveded with median	No	Both sides	Commertial next to CBD	Medium	40
5	-Mid-block -Local road	One-way two-lane undivided	No	No	Commertial next to CBD	Low	40
6	-Mid-block -Arterial road -In front of school	4-lane divided with median	No	No	Residential	Heavy	40

STUDIED LOCATIONS

Six different urban locations in Irbid-Jordan having serious pedestrian crash problems were studied. Table (1) shows descriptive statistics for the studied locations. The following criteria were used to select these locations:

1. Locations distributed all over Irbid city representing different zones (variable land use) such as: school zones, mid-block zones, signalized (3 phases) and unsignalized intersection zones, … etc.
2. Study areas located in crowded commercial or

residential areas.

3. Locations having different traffic volumes: heavy, medium or low.
4. Study areas historically having conflicts between pedestrians and traffic and high rates of pedestrian crashes.
5. Study areas having available and accessible crash records at the police department.

The recording time of pedestrian-traffic conflicts was at the peak hours (7:00 a.m. to 9:00 a.m. and 1:00 p.m. to 3:00 p.m.).

It is worthwhile mentioning here that some of the locations were filmed twice in order to understand the behavioral response of conflict between pedestrians and traffic. Studying these conflicts and knowing the reasons behind them may help to reduce the hazard while crossing the road, and it will reduce the suffering from injury, death and property damage. Thus, this will give guidelines for planners to control pedestrian crossing and to design different traffic control devices.

The crossing behavior of pedestrians in the studied locations was concentrated at the filmed field of view in case of pedestrian crossing facility existence; however, it was dispersed crossing at the mid-blocks locations of no pedestrian crossing facilities. The vehicle speed affected the crossing behavior of pedestrians either to wait at the side walk, cross at steep or mild angle, slow down, wait at the median, return back or stop at a point while crossing the road.

DATA COLLECTION

Using normal-based photography to capture vehicle-pedestrian conflicts has many advantages such as: time saving, less labor work and accurate measurement potential. It also gives continuous mapping of pedestrian crossing as function of time. Thus, it is possible to plot conflict diagrams between vehicles moving along the road and the pedestrians crossing the road.

Collected data for this research were categorized into three categories including:

1. Vehicle related data;
2. Pedestrian related data;
3. Geometry and location data.

Collected data were also divided into:

1. Data measured using the PC-based vision system;
2. Data collected by human operator observation with the aid of PC-based vision system.

Measured data and images were automatically processed using image processing software associated with the used vision system (EPIX 1993). These quantitative variables, for every vehicle-pedestrian potential conflict at all studied locations, included:

1. Image coordinates of vehicles through its path along the road, in the field of view of the traffic camera, having high potential conflict with pedestrians. The x-coordinates of vehicle images were recorded while having the camera in the playback mode then in the pause mode for every 1/3 second; i.e. a frame of every 20 frames. A point on the hood of the vehicle was selected as a reference point for measurements.
2. Image coordinates of pedestrians across the road, in the field of view of the pedestrian camera, having potential conflict with the same vehicle appearing in the traffic camera. The time, which was common between the traffic and pedestrian cameras, was used to control the pedestrian-vehicle conflict. The x-coordinate of pedestrian was recorded for every 1/3 second; i.e. a frame of every 20 frames. A pedestrian's foot or any visible part of his/ her body was used as a reference point for measurements.
3. Image coordinates of the two ends of road width, sidewalk and median.
4. Start and end points of image coordinates for every pedestrian crossing the road using the pedestrian camera (x-coordinates); i.e. to be called *W*, and the x-coordinates at the same two points (the start and end of crossing) at the traffic camera; i.e. to be called *L*. These measurements make it possible to compute the crossing angle (θ) of pedestrians based on the following equation:
   $$\theta = \tan^{-1}(L/W) \qquad (2)$$
5. Time for every 1/3 second in both cameras for vehicle

and pedestrian movements. Thus, knowing the coordinates and time, the speeds of pedestrians as well as that of vehicles could be computed for every 1/3 second.

6. Vehicle distance (D_v) from the pedestrian crossing the road. This requires the coordinates of the pedestrian and the vehicle on the traffic camera.
7. Number of lanes in each direction of the road. This could be known by measuring the x-coordinates of the image of the two ends of the road in each direction from the pedestrian camera and dividing the total crossed width by the lane's width. The number of lanes was also available since the studied sites were known, however, this information was useful to know the direction and angle of pedestrian crossing.

The data observed by human operators with the aid of PC-based vision system included:

1. Type of vehicle: heavy vehicle (truck or bus) or passenger vehicle.
2. Divided or undivided road geometry.
3. Commercial or residential land use for the study area.
4. Study area location at an intersection or mid-block.
5. Availability of pedestrian facility such as: crosswalk and pedestrian crossing facility.
6. Estimated age of pedestrian.
7. Gender of pedestrian.

The extracted data using human operator observation was approximate and used for comparison purposes to check their reliabilities with the data collected manually in the field.

DATABASE AND DESCRIPTION OF VARIABLES

Eleven independent variables were investigated to predict the pedestrian speed as the dependent variable. 3317 sub-point locations at the profile of pedestrian crossing in the six locations were used in this study. The following are the definitions of the independent and dependent variables used:

1. Vehicle speed (V_v): This variable was measured continuously as a function of time for every vehicle having potential conflict with the pedestrians crossing the road while the vehicle was moving along the same road. Speed was recorded for a frame of every one-third of a second. These speeds were found by knowing the distance between the vehicle and the pedestrian at two times representing the start and the final time associated with the vehicle in the field-of-view of the camera. Then, the speed is distance divided by the time.
2. Distance of vehicle (D_v): This is the distance up to one pixel along the road between the moving vehicle and the projected pedestrian distance while crossing the road.
3. Distance of pedestrian (D_p): This distance was continuously measured as a function of time from the road shoulder, where the pedestrian started to cross the road to the final point reached.
4. Angle of crossing (A_g): This was the crossing angle for the path of pedestrians with respect to the line perpendicular with the passing traffic. The crossing angle for every pedestrian was reported to be positive when the pedestrian goes far away from the vehicle, however, it was negative when a pedestrian goes toward the vehicle.
5. Type of vehicle (T_v): Two types of vehicles were considered here: the passenger vehicles and the heavy vehicles. The heavy vehicles were mini-busses and heavier vehicles. They were recognized and observed by a human operator vision using a video camera. This variable was recorded as a dummy variable: one for passenger vehicles and zero for heavy vehicles.
6. Road geometry (G): Two types of road geometry were considered: divided or undivided roads. This variable was recorded as a dummy variable: one for divided roads and zero for undivided roads.
7. Land use (L_u): The studied locations were categorized into two types of land use: commercial or residential. This variable was recorded as a dummy variable: one for the roads located next to commercial areas and zero for the roads located next to residential areas.
8. Location (L): This variable gives an indication of whether the studied location was at an intersection or mid-block. This variable was recorded as a dummy

variable: one for mid-block and zero for intersections.

9. Pedestrian facility (F_p): This variable gives an indication of the existence or absence of crosswalks for pedestrians. It was recorded as a dummy variable: one in case of crosswalk existence and zero in case of crosswalk unavailability.
10. Age of pedestrian (A): Ages of pedestrians were grouped into 5 year ranges.
11. Gender of pedestrian (G_d): This variable was recorded as a dummy variable: one for males and zero for females.
12. Pedestrian speed (V_p): This was the dependent variable. It was computed continuously as a function of time for every pedestrian who makes potential conflict with the vehicle moving along the road. Frame by frame analysis was used to compute this variable by recording the differences between two successive distances and their respective associated times. Table (2) shows the statistical characteristics of the variables included in the analysis.

Table 2: Statistical Characteristics of the Variables.

Variable	Observed Data	Mean	Standard Deviation	Range	
				Min.	Max.
Pedestrian speed (V_p); (m/sec.)	3317	1.215	0.967	0	8.27
Vehicle speed (V_v)); (m/sec.)	3317	4.301	4.286	2.47	26.63
Distance of Vehicle (D_v); meter	3317	15	11.246	0	41.49
Type of Vehicle (T_v)	3317	0.67	0.47	0	1
Geometry (G)	3317	0.585	0.493	0	1
Land Use ($L_{u)}$	3317	0.605	0.489	0	1
Location (L)	3317	0.454	0.498	0	1
Pedestrian Facility (F_p)	3317	0.409	0.492	0	1
Pedestrian Distance (D_p); meter	3317	10.185	5.497	0	22
Age (A); year	3317	24.437	10.909	7	60
Gender ($G_{d)}$	3317	0.576	0.494	0	1
Angle of Crossing (A_g); degree	3317	15.152	21.427	-90	90

SPEED PROFILES

Figure (2) predicts the speed profiles of the vehicle's speed and pedestrian's speed for a sample studied location. The frequencies of vehicles having this relationship were 77, 31, 72, 28, 68 and 39 for the six locations, respectively. Other relationships such as that between the pedestrian's distance (D_p) and the pedestrian's speed (V_p), and the vehicle's distance (D_v) and the vehicle's speed (V_v) could give a good idea about the changes in pedestrian's speed as functions of vehicle's speed, vehicle's distance along the road and pedestrian's distance while crossing the road. Thus, it will be an aid for statistical analysis modeling because human behavior while crossing or driving was neither consistent nor easy to be predicted.

DEVELOPMENT OF PEDESTRIAN SPEED MODEL

Selection of Models

The previous independent variables were selected and identified based on the following criteria:

1. Development of coefficient of linear correlation matrices among all related variables. This step is of great importance in the selection of variables and that might significantly affect the expected relationship.
2. Drawing of scatter plots to show the pattern of relationships among variables and various observations related to the investigated variables.
3. Stepwise analysis to select the most significant variables.

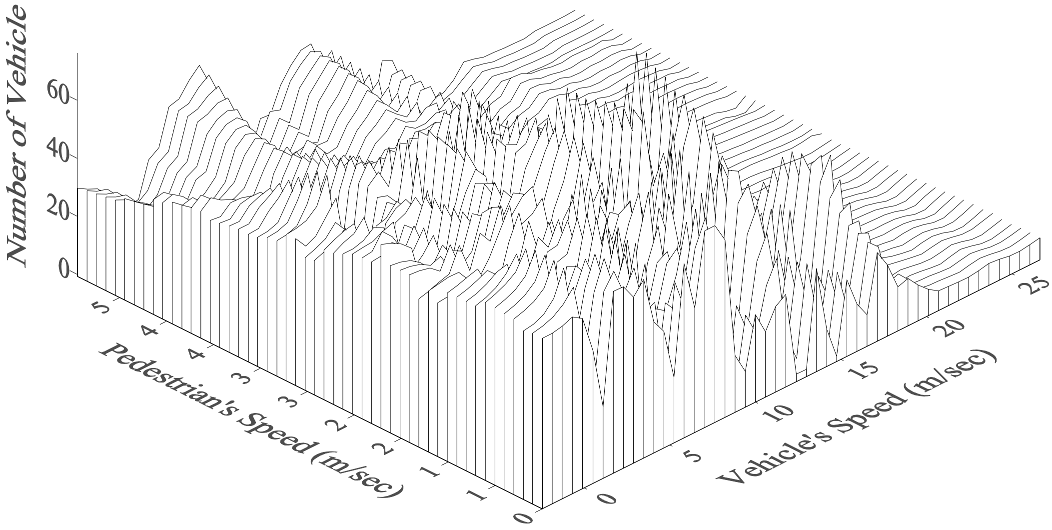

Figure 2: Vehicle's speed versus pedestrian's speed for a studied location.

The first step in model development was the establishment of correlation matrices among variables. These matrices are of great importance in selecting the independent variables, and in checking the multi-collinearity between independent variables. The next step was drawing of scatter plots to describe the general trend of expected relationships in order to determine the required statistical transformations. Finally, several statistical regression analyses were performed to develop the best statistical models.

The statistical analysis system (SPSS) computer package available at the PC of the Surveying and Photogrammetry Laboratory at Jordan University of Science and Technology (JUST) was used in all stages of model development.

The following was adopted to check the suitability of the developed models.

1. Coefficient of multiple determination (R^2), which determines the general goodness of fit of the developed model. The adjusted coefficient of multiple determination (R^2-adj) should be closer to R^2 in order to represent the strength of the model.
2. The general linearity tests for the model. Its corresponding variables are represented by F-value and T-value, respectively.
3. The significance of the independent variables that meet the pre-selected α-level.
4. Standard error of estimate. Small values of standard error of regression models indicate that the relationship is satisfactory.
5. Consistency and normality of error terms. Constant variance and normal distribution of residuals represent good predictable models.

MODELING AND RESULTS OF ANALYSIS

A linear multiple regression between pedestrian speed and the independent variables was developed using the database of this study. The developed relationship was as follow:

$$V_p = -0.211 (V_v) - 0.0128 *(D_v) - 6.04 *(G) -1.462 * (L_u) + 3.132 (L) + 0.217 * (F_p) + 9.166 \quad (3)$$

Where; V_P = Pedestrian speed; V_v = Vehicle speed; G_d = Gender of pedestrian; D_v = Distance of vehicle; G = Geometry of the road; L_u = Land use of the area; L = Location of the road; and F_p = Pedestrian facility.

Table 3: Analysis of Variance for Stepwise Regression (ANOVA Results).

Step Number	Used Variables	Model	Sum of Squares	Degree of Freedom (DF)	Mean Square	F	Significance
1	G	Regression	271.1	1	271.1	317.4	0.000
		Residual	2830.7	3316	0.854		
		Total	3101.8	3317			
2	G and V_v	Regression	328.9	2	164.5	196.5	0.000
		Residual	2772.9	3315	0.837		
		Total	3101.8	3317			
3	G, V_v and L	Regression	369.2	3	123.1	149.2	0.000
		Residual	2732.6	3314	0.825		
		Total	3101.8	3317			
4	G, V_v, L and L_u	Regression	399.9	4	99.9	122.5	0.000
		Residual	2701.9	3313	0.816		
		Total	3101.8	3317			
5	G, V_v, L, D_v and L_u	Regression	402.3	5	80.5	98.7	0.000
		Residual	2699.5	3312	0.816		
		Total	3101.8	3317			
6	G, V_v, L, D_v, L_u and F_p	Regression	403.7	6	67.3	82.5	0.000
		Residual	2698.1	3311	0.815		
		Total	3101.8	3317			

Table 4: Variables of the Linear Multiple Regression Model and their Respective T-values.

Variable	T-value
V_v (m/sec)	-27.18
G_d	-4.283
D_v (m)	-11.824
G	-25.649
L_u	-7.96
L	20.643
F_p	12.387
Constant	26.364

Table (3) lists the analysis of variance for the stepwise regression (ANOVA), while Table (4) shows the variables of the linear model and their respective T-values. Figure (3) shows the normal probability of regression residual, which indicates that the residual didn't depart from normality. Therefore, the linear regression analysis was appropriate. The developed model was statistically significant with the coefficient of multiple regression determination (R^2) = 0.38664. This means that about 38.664% of V_p variation can be explained by the included independent variables. The coefficient of multiple determination was very close to adjusted coefficient of multiple determination, which suggests that the model is strong and predictable. The model had a small standard error of estimate.

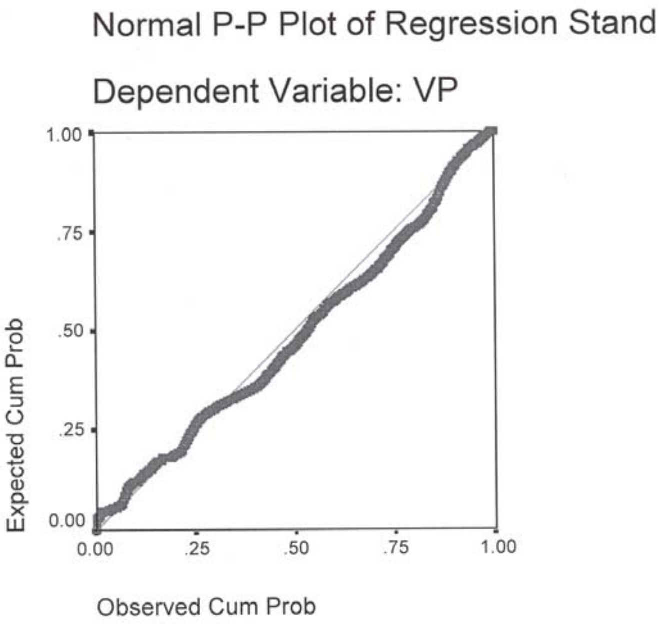

Figure 3: Normal probability of regression residual.

This model shows that the pedestrian speed, which is a measure for pedestrian behavior, could be predicted if the following variables are known: the vehicle's speed, the gender of pedestrian, the distance of the vehicle, the geometry of the road, the land use of the area, the location of the road and the pedestrian facility.

This model was found to be the best model to represent the relationship between the pedestrian's speed and the listed independent variables. Other models such as exponential and logarithmic models were found statistically significant with coefficient of multiple determination (R^2) of 0.15481 and 0.12892, respectively.

DISCUSSION OF RESULTS

Six different locations were investigated to estimate the pedestrian's speed as a measure of pedestrian's behavior. The database was extracted using the PC-based vision system. Twelve variables, of which eleven are independent variables, were used to build a useful statistical prediction model. Speed profiles of vehicles and pedestrians showed that the pedestrian's behavior started with high speed then decreased in conflict as soon as the vehicle became closer to the pedestrian. In fact, vehicles tend to stop at crowded crossing areas such as school zones.

Field observations as well as data analysis through video cameras showed the following:

1) Scatter plots of all variables did not give a clear idea about the type of relationships that relate the dependent variable with the independent variables. This was due to the fact that pedestrian's behavior varied for every one because the type of behavior

sometimes is not correlated to the vehicle movement. For example, a pedestrian might decrease or increase his/her speed, or cross at an angle due to his/ her mood rather than the vehicle's effect. Figure (4) shows the scatter plot between V_P and V_V. There was no clear trend or relationship between the speed of the vehicle and the speed of the pedestrian. This would be an indicator of that the relationships and correlation between most of the variables - which are complicated - affect the goodness of fit of the developed model. Statistical transformation of variables was not needed.

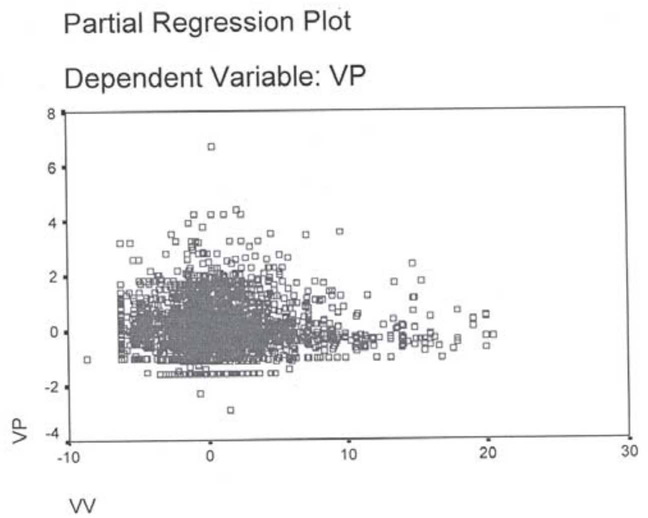

Figure 4: Scatter plot for pedestrian speed and vehicle speed.

2) Large number of data observation had an effect on the statistical analysis modeling. This study included 3317 data observations. Therefore, the variability in the data was too high.

3) Low value of (R^2) was due to the behavioral characteristics of pedestrians while crossing the road. Therefore, psychological effects and moods might be needed to study why the pedestrian made that type or way of crossing. Other factors which might be included are trip types and different physical capabilities. The behaviors of pedestrians and drivers were not consistent because it was not easy to define the exact variables that control the behavior of humans. Moreover, approximated variables such as age could affect the results.

4) Having (R^2) of about 0.39 means that the variation in pedestrian speed can be explained by the included independent variables in the linear model. Other variables such as education of pedestrian, mood of pedestrian, weather conditions, pedestrian's physical ability, trip purpose, gradient of walkway and technical knowledge about driving if incorporated to the developed model might increase the R^2, however, it was extremely difficult to have them for every pedestrian crossing the road.

5) Females tend to cross more quickly and conscious than males.

6) Due to high conflict numbers in commercial areas, vehicle's speed and pedestrian's speed tend to slow down in residential areas.

7) It was safer to cross the road in case of divided roads than in undivided roads because the pedestrian estimated a shorter distance to cross and the crossed distance is divided into two stages with a rest in between at the median.

8) Curiosity of pedestrians at intersections lead to a decrease in their speeds more than at mid-block crossing, since pedestrians had to watch out for traffic

from all directions.

9) Neither the exponential model nor the logarithmic model could describe the relationship between pedestrian's behavior and the studied independent variables. However, the linear regression model represented this relationship with an (R^2) of 0.39.
10) The age of pedestrian does not affect the behavior of the pedestrian since the bulk categories for age were from 30 up to 40 years old.
11) Conflict term means the possibility of having a crash. It's a qualitative measure which can be described by noticing the different speed profiles for the vehicles and pedestrians; i.e. the vehicle will affect the speed profile of the pedestrian.

PRACTICAL APPLICATIONS

The developed linear model could help and provide the planners and traffic engineers with a reasonable estimate for pedestrian speed and overcome the problems associated with pedestrian crossing. Further, the behavior of pedestrian while crossing the road will be more understood. This could provide guidelines for planners in the city and/or traffic engineers and related agencies.

The statistical analysis also gave the important factors affecting the pedestrian's speed. Finally, by knowing the pedestrian's speed, an indication about conflict problems and crash potentials could be given. Therefore, planners will try their best to reduce the number of conflicts and thus enhance safety and reduce hazard.

EXPERT SYSTEM DEVELOPMENT

The development of an interactive educational system to give school students an idea when and where to cross the road safely is essential. Thus, application of Artificial Intelligence (AI) and knowledge-based systems to tasks that need decision-making has the potential to induce more users to employ new schemes for successfull road crossing. The key to the problem solving here is to represent the knowledge directly in the form of heuristic *IF… THEN* rules.

A knowledge-based system has been developed to assist users in making safe road crossing for different road geometry, traffic characteristics and pedestrian behavior. Its purpose is to automate much of the decision-making functions to model the behavior of pedestrians while performing road crossing. The decision-making process in this domain yields a result to cross the road safely.

Functions and Tasks

The knowledge-based system was developed to aid pedestrians to safely cross the road with potential traffic-pedestrian conflicts. The following functions and objectives represent the core of the developed system:

1. Assist the road users, especially the elementary school students, to perform safe road crossing.
2. Perform user counseling in case of unsafe road crossing conditions.
3. Assist in decision making to accept or reject the results of road crossing based on a set of *IF… THEN* rules.
4. Perform a list of *IF… THEN* rules for pedestrian road crossing, including: hypotheses, rules or facts, decision-making and reasoning.
5. Develop an ease-of-use system for non-experienced users and automate rules and criteria for pedestrian road crossing.
6. Obtain accurate measures for pedestrian speed and traffic characteristics while road crossing.
7. Minimize pedestrian hazard. Therefore, conflicts (potential of crash) between pedestrians and vehicles are anticipated to be reduced.

The developed expert system was designed and organized in a simple and efficient way to help non-expert users such as school students to decide whether it is safe to cross the road or not. It helps experts in assessing the various variables needed to calculate the required parameters in order to make a correct decision to maintain automated safe road crossing. It calls upon knowledge obtained from experts and from literature, such as American Society of State Highway and Transportation Officials (AASHTO) and asks for supplementary information needed. The developed expert system used the knowledge base and an inference engine of the VP-Expert shell (Richard and Mar, 1988).

Expert System Methodology

The judgment of pedestrian crossing can be dependent on time determination and gap time between two successive vehicles following each other to permit the pedestrian to finish his road crossing with a safety factor before making conflict with the following vehicle. Sometimes, the crossing also depends on braking distance of vehicle, color of signal and waiting time acceptance. Some people accept much longer waiting times, in the range of minutes, while others are eager to cross if they have waited more than 30 seconds. Therefore, the rules that can be undertaken in our expert system must rely upon these facts.

Table 5: Age and Speed of Pedestrians (Bowman and Vecellio, 1992).

Age (year)	Pedestrian Speed (ft/sec)
<12	0.75
12≤age≤30	5
30<age≤45	3
>45	1.5

The criterion used to give decision for the pedestrian to safely cross the road is to have the time required for a vehicle to pass along a section greater than the required time for the pedestrian to cross the road for a threshold value of about five seconds. Otherwise, the possibility of having a potential crash is increased.

In order to calculate the time required for a pedestrian to cross the road, the number of lanes and their widths, and the existence of a median and its width have to be known. Therefore, the crossing distance should be known. Then, knowing the age of the pedestrian, his/ her average speed can be predicted from Table (5). Thus, knowing the width of the crossing distance and the speed of the pedestrian, the required time for the pedestrian to cross the road (t_p) can be computed.

The determination of the corresponding time traveled by the vehicle (t_v) while the pedestrian is crossing the road can be found using one of the following approaches:

1. Vision system approach.
2. Posted speed approach.
3. 85th percentile speed (V85th).

Expert system users could use any of these methods, however, the system automatically finds the maximum speed of vehicle of the three methods to assure safe pedestrian crossing. At least a five seconds threshold value was selected for the difference between t_v and t_p to avoid collision between pedestrian and vehicle (Bowmen and Vecellio, 1992). Therefore, safe road crossing will occur.

There are some factors that affect the computed time of pedestrian road crossing (t_p) including: existence of median, lane closing due to working zone existence, crossing angle, sidewalk existence, signal existence and curvature of horizontal alignment. If the median width is greater than or equal to four feet, the distance traveled by a pedestrian while crossing the road may be computed using the following equation:

$$d_p = [\,[(n * L - M_W)]/[\cos\theta]]/\,2 \qquad (4)$$

where; d_p= Pedestrian distance (m); n = Number of lanes in both directions; L = Lane width (m); M_W = Median width (m); and θ = Crossing angle (degree).

However, in case of median width less than four feet, median width in Equation (4) is substituted to be zero to be in the safe side. The existence of working zone reduces the crossing distance by the width of the working- zone lanes. Further, if the crossing exists next to a signalized intersection, human operator observation is required to see the signal color. Then, if it is red for vehicles it will be safe to cross the road. In case of pedestrian phase existence, a pedestrian has to wait until seeing the green color for pedestrians.

Decision trees were designed taking into consideration the previous factors. Facts and rules were also generated. Figure (5) shows the developed expert system components.

Input and Output of the Expert System

Sets of data input for the knowledge-based system are as follows:

1. Number of lanes and lane width.
2. Type of intersection (signalized or unsignalized).
3. Radius of curvature at curves.
4. Coordinates for start and end positions of the vehicle along the road corresponding to the start and end points of the pedestrian crossing the road.
5. Posted speed.
6. Age and gender of the pedestrian.
7. Number of closed lanes in case of a work zone.
8. Grade of the road (%).
9. Superelevation rate at curves (e%).
10. Travel time between start and end points of the vehicle corresponding to the time of start and end points of the pedestrian crossing across the road.
11. AASHTO policy tables for curvature, speed, superelevation and friction.
12. Type of school (indicator for age of students) in case of crossing in front of a school.
13. Length of road section; i.e. the vehicle distance traveled by a vehicle along the road.
14. Crossing angle.
15. Width of crosswalk.
16. Friction coefficient value (f).

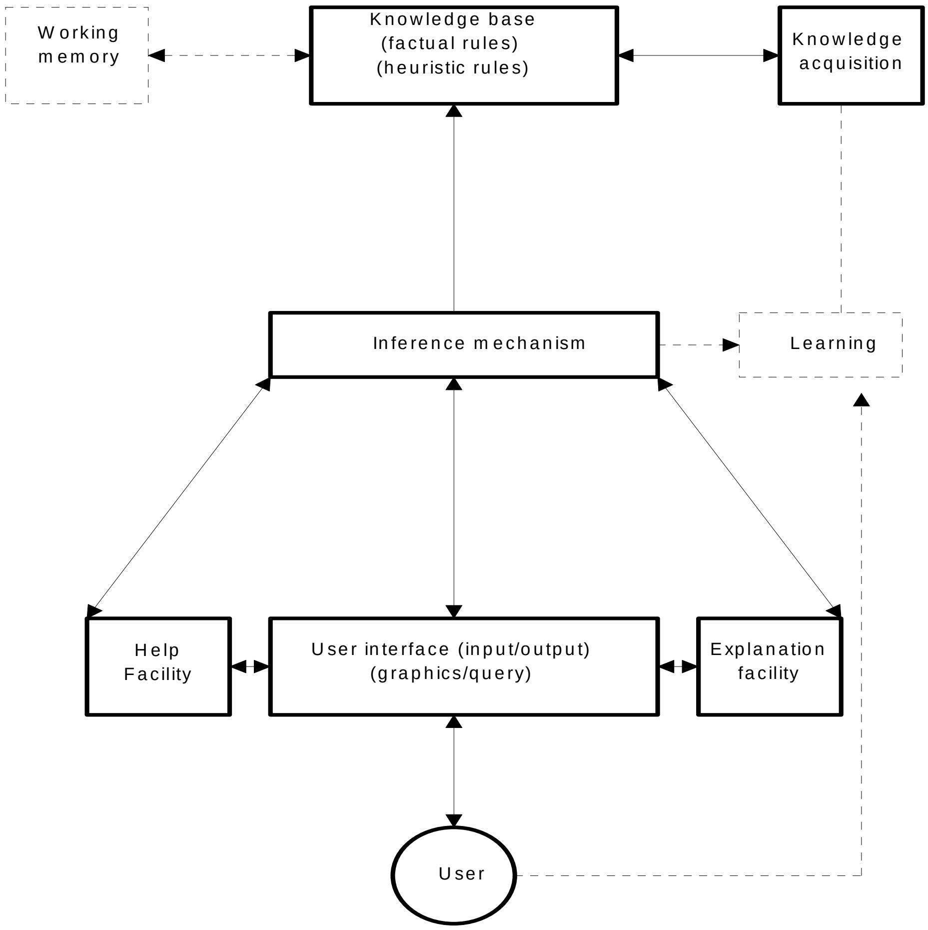

Figure 5: Expert system components.

After answering a set of questions containing the previous input data, the backward chaining system of the shell can give a conclusion. The output of the developed expert system was the decision for safely crossing the road or not.

Set of Rules

In the VP-Expert shell, all the determinations that give check for pedestrians were represented in the forms of GT= greater than; EQ= equal; OR= the logic statement (or); AND= the logic statement (and); LE= less than or equal; ELSE= all other possibilities excluding the listed ones.

Example of a Rule

Specific Goal: Determination of vehicle speed along the road (V_v) if normal-based vision system mapping is used.

Input: X-coordinate of the start point of the moving vehicle (X_{v1}), X-coordinate of the end point of the same vehicle (X_{v2}), and the start (t_{v1}) and end times (t_{v2}) in seconds associated with the previous two coordinates.

IF: Normal-based vision mapping availability =Yes, AND X_{v1}.GT.0, AND X_{v2}.GT.0, AND t_{v1}.GT.0, AND t_{v2}.GT.0.

THEN: Vehicle distance along the road (d_v) = (X_{v2}-X_{v1}), time required for the vehicle to travel this distance (t_v) = (t_{v2}-t_{v1}), and vehicle speed (V_v)= (d_v/t_v).

Validation of Expert System

The developed expert system was successfully evaluated through its capability for detecting errors in data input, data processing and decision-making. During the validation process it was meant to include all variables affecting the pedestrian crossing in failure or success mode of crossing.

The developed expert system was validated and tested at two elementary schools (one for males and the other for females) to help non-experienced students take decisions related to road crossing and awareness for pedestrians. Through educational demonstration of successful roadway crossing, the system helped the students a lot in the domain of pedestrian awareness that improved their pedestrian crossing capabilities. Of course, training pedestrians to cross more safely shouldn't include the judgment of all the studied parameters, however, the parameters would give clues or ideas for non-experienced pedestrians to enhance their crossing judgment capabilities.

The system was tested and validated for the following eight cases:

1) Case 1: Crossing occurred at a two-lane undivided highway (Straight-line crossing).
2) Case 2: Crossing didn't occur at a two-lane undivided highway (Straight crossing).
3) Case 3: Crossing occurred at a two-lane undivided highway (Angle crossing).
4) Case 4: Crossing didn't occur at a two-lane undivided highway (Angle crossing).
5) Case 5: Crossing occurred at a two-lane undivided highway (Crosswalk Existence).
6) Case 6: Crossing didn't occur at a two-lane undivided highway (Crosswalk Existence).
7) Case 7: Crossing the road next to a signalized intersection.
8) Case 8: Crossing didn't occur next to a signalized intersection.

Validation Example

The following example demonstrates the validation procedure for a case of the eight different pedestrian crossing cases in which actual safe pedestrian crossing did not occur and is detected by the expert system to be unsafe crossing:

Input: two-lane highway @3 m, pedestrian age = 30 years, X-coordinates for start and end points for the vehicle; i.e. X_{v1} and X_{v2}, respectively, and the start and end time for the vehicle; i.e. t_{v1} and t_{v2}, respectively.

Processing:

-Pedestrian crossing distance (P_D)= (2*3)= 6 m.

-Knowing the age of the pedestrian, pedestrian speed (V_p) is 5 m/sec.

-Required time for the pedestrian to cross the road (t_p) = 6/5 = 1.2 seconds.

-X_{v1}= 14 m; X_{v2}= 33 m; t_{v1}= 3 seconds; and t_{v2}= 7 seconds.

-Required time for the vehicle to cross the road (t_v)= 7-3= 4 seconds.

-Difference in time between the pedestrian and vehicle (d_{vp}) = (4- 1.2).

= 2.8 seconds. It is less than the threshold value.

Decision of expert system: it is not safe to cross the road under these conditions.

Actual Human Operator Observation of Crossing: The pedestrian did not cross the road.

CONCLUSIONS

The following main conclusions were the most significant findings:

1. The linear multiple regression model was found to be the most significant model to predict the relationship between pedestrian speed and other variables related to vehicle, pedestrian and road geometry.
2. Vehicle speed, gender of pedestrian, distance of vehicle, geometry of the road, land use and location of the road and pedestrian facility variables were found to be the most significant contributors to pedestrian speed while crossing the road.
3. Angle of crossing, age of pedestrian, type of vehicle and pedestrian distance were found to have a non-significant contribution to pedestrian behavior while crossing the road.
4. Normal-base camera setup has proven to be a useful, practical and accurate data acquisition system for pedestrian and traffic studies.
5. Conflict between vehicle and pedestrian could be used as an indicator for pedestrian crashes.
6. Expert systems were proven to be useful educational systems to assist non-experienced pedestrians to perform decisions regarding safe road crossing.

While the feasibility of this setup along with statistical analysis modeling and expert systems in studying vehicle-pedestrian conflict had been demonstrated, the following areas may deserve further study:

1. Other variables should be investigated to study pedestrian behavior while crossing the roadway including: educational level, pedestrian bagging, physical ability, trip purpose, weather conditions and gradients of walkway and roadway.
2. Further research work should be held in order to study the effect of: scale, resolution, camera type and its stability with time and image matching on using vision system for the purpose of automatic data acquisition systems.
3. Further research should be conducted to provide the planners and traffic engineers with a reasonable estimate for pedestrian speed and overcome the problems associated with pedestrian crossing.
4. Further studies should be conducted to expand the usage of normal-based camera setup and expert systems in traffic engineering studies.

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