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MODELLING THE PEDESTRIAN CROSSING SPEED USING FUZZY LOGIC

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ABSTRACT

Despite all the measures taken, highway traffic accidents have an ever increasing trend in Turkey. In 2017, 1.202.726 traffic accidents occurred in Turkey, resulting in 7.427 deaths and 300.383 injuries. The pedestrian faults in this accidents have a share of 8.3%. The majority of these accidents occur when the pedestrians share the road with the motor vehicles. Pedestrian crossings are designed or the motor vehicle traffic is stopped using traffic lights for safe crossing of pedestrians. However, in most cases, the duration of the traffic lights is determined only by taking into account the motor vehicle traffic parameters, ignoring the crossing speeds of the pedestrians. In this study, pedestrian crossings were examined at different intersections on the Anatolian side of Istanbul, which was selected as pilot region. Using the data obtained, pedestrian crossing speeds are modelled using fuzzy logic, taking into consideration the individual characteristics, weather conditions, traffic conditions and time conditions. Using the developed model, the time that pedestrians need to cross the street can be determined in advance. In this way, more appropriate pedestrian crossing designs can be made or a real-time traffic control system which takes the pedestrian traffic into account realistically can be designed.

INTRODUCTION

Despite all the measures taken today in Turkey, traffic accidents are increasing and these accidents are at the top of the social problems. In 2017, 1.202.726 traffic accidents occurred in Turkey, resulting in 7.427 deaths and 300.383 injuries (KGM, 2018). The number of traffic accidents per year has almost doubled in the last 10 years. Although there are discussions about the reliability of the statistics recorded, the human is the faulty factor on 99% of the traffic accidents occurred in the last 10 years. Within the framework of Road Traffic Regulations of the Highway Traffic Law No. 2918 that entered into force on April 1, 2008, in the case of traffic accidents resulting in material loss only, the parties may be separated from the scene by holding a record, without waiting for legal officers. For this reason, the data obtained since 2008 are prepared only by taking into account the information related accidents involving death and personal injury. Pedestrians were found faulty on the 8.3% of the 182.669 accidents involving death and personal injury occurred in 2017. Pedestrians are the one of the vulnerable road users and the physical damage obtained after an accident is more severe than the accidents between motor vehicles. For this reason, the measures taken against traffic accidents involving pedestrians will be an important factor to significantly reduce the traffic accidents involving death and personal injury.

Pedestrians perform their journey on the sidewalks, which are reserved for their movements only. However, pedestrians are most likely to be involved in a traffic accident during street crossings where they have to share highways with vehicles. Pedestrian crossings are designed or the motor vehicle traffic is stopped using traffic lights for safe crossing of pedestrians. Even if motor vehicle traffic is stopped by traffic lights for pedestrian crossings, only vehicle traffic values are taken into account even in signal timings and pedestrian speed and density are mostly ignored. For this reason, the time allocated for pedestrian crossing can be longer or shorter than the necessary value. In determining the location and dimensions of pedestrian crossings, as well as traffic signal timings, investigating the pedestrian crossing speeds will be an important factor in traffic safety.

The pedestrian crossing speed is one of the subjects that capture the interest of researchers. Because pedestrian walking speed is an important criterion in the design of various engineering structures. The walking movement of pedestrians either alone (Knoblauch et.al., 1996, Asano et.al, 2010) or within a group (Duives et.al, 2013) is being used as a data in various areas such as getting on and off the metro wagons (Zhang, et.al., 2008), station and platform design (Ding et.al., 2011), stairs design (Burghardt et.al., 2013) and emergency evacuation (Shiwakoti and Sarvi, 2013). However, the street crossing behavior and thus the street crossing speed of pedestrians differ than their normal walking behavior and speed (Montufar, et.al., 2007, Chandra and Bharti, 2013). For this reason, it would be a more accurate approach to investigate and use them as a data in the design of transportation structures.

There are several studies conducted in different countries on the pedestrian crossing speed. The Traffic Engineering Handbook suggests taking pedestrian crossing design speed as 0.91 - 0.98 m/s (Dewar, 1992). The Institute of Transportation Engineers recommends a value of 0.75 m/s for areas with high density of elderly pedestrians (ITE Committee 4A-6, 1983). The Manual of Uniform Traffic Control for Street and Highways recommends using a single value of 1.21 m/s as pedestrian crossing speed (FHWA, 2003).

In the literature, a number of factors effecting the pedestrian crossing speed have been investigated. The researches show that the pedestrian crossing speed decreases with the advancing age and the males were found more likely to cross faster than females. In addition, most researchers indicate that it is appropriate to use the 15th percentile speed, in other words the speed value that 15% of pedestrians do not exceed, as the design speed. As can be seen in Table 1, street crossing speeds between 0.75-1.45 m/s are recommended as a result of studies conducted in different countries (Rastogi, 2011). A more recent study conducted in Turkey reveals the average pedestrian crossing speed as 1.20 m/s in Istanbul (Dündar, 2013) and 1.31 m/s in Izmir (Önelçin and Alver, 2016). When compared to similar studies, the street crossing speed found lower in Turkey. Investigating the reasons for this and preparing the traffic regulations accordingly are crucial for road traffic safety.

Table 1. Street crossing speed of pedestrians with respect to their age and gender (Rastogi, 2011)

		Average speed (m/s)				15th percentile speed (m/s)	
Reference	Country	Adult	Elderly	Male	Female	Adult	Elderly
Siöstedt. 1967	UK	1.44	1.14	-	-	1.14	1.04
DiPietro and King, 1970	-	-	-	0,67^{b}	0,58^{b}	0,76^{a}	-
Cresswell and Hunt., 1979	UK	1,57	1,11	-	-	-	-
Wilson and Grayson, 1980	UK	1,32	1,13	1,32	1,27	-	-
Griffiths et.al, 1984	UK	1,47	1,16	-	-	-	-
Tanaboriboon and Guyano, 1991	Bangkok	-	-	1,31	1,23	-	-
Bowman and Vecellio, 1994	Sweden	1,45^{a}	1,03	-		0,70^{a}	-
Coffin and Morrall, 1995	Canada	-	1,27	-	-	-	1,00
Knoblauch et.al., 1996	USA	1,51	1,25	-	-	1,25	0,97
Guerrier and Jolibois, 1998	ABD	1,35	0,97	-	-	1,00	0,67
TRB, 2000	-	-	1,0	-	-	-	-
Tarawneh, 2001	Jordan	1,47	1,17	1,35	1,33	1,22	0,97
Gate, et.al., 2006	USA	1,44^{a}	1,16	1,47	1,40	1,22	0,92
Fitzpatric, et.al., 2006	USA	1,45	1,34	-	-	1,17	0,97
Daamen and Hoogendorn, 2007	Holland	-	1,24	-	1,18^{c}	-	-

^{a}Average speed
^{b}15th percentile speed
^{c}Elderly woman

MATERIALS AND METHODS

In this study, it has been tried to determine the pedestrian crossing speeds and the factors affecting them. The pilot region has been selected as Istanbul since it is the most populous city of Turkey. The pedestrian crossing behavior were recorded using video cameras placed in locations close to the various signalized intersections having different properties. In order to avoid curiosity of pedestrians, the cameras were positioned out of sight of the crossing pedestrians. The analysis of the recordings obtained at different times, different weather and traffic conditions were performed in the laboratory. In the recordings obtained, the crossing time of each pedestrian was measured by starting a timer at the moment when the pedestrian got off the sidewalk and stopping it at the moment when he/she got on the sidewalk on the opposite side. The crossing speed of each pedestrian was obtained by dividing the road cross section width into the crossing time. A total of 5.098 individual crossing speeds were measured from the obtained video recordings.

In order to model the pedestrian crossing speed, it is necessary to determine the criteria affecting it. Therefore, in the scope of this study the criteria affecting the crossing speed are collected under the main factors, such as individual characteristics, timing measures, weather, location and traffic conditions. Statistical analyzes were performed with IBM ® SPSS® Statistics 22 software.

Effect of the Individual Characteristics on the Pedestrian Crossing Speed

The individual characteristics that may affect the pedestrian crossing speed are gender, age, distraction, disability status and whether crossing alone or in a group.

The gender of the crossing person, as male or female is directly obtained from the camera recordings. 2.612 of the street crossings were performed by males, with the remaining 2.486 by females. An independent-samples t-test was conducted to compare the crossing speeds of male and female pedestrians. There was a significant difference in the scores for male ($M = 1.33444$, $SD = 0.49087$) and female ($M = 1.2788$, $SD = 0.43635$) conditions; $t(5096) = 4.262$, $p = 0.000$. These results show that, male pedestrians cross significantly faster than females in Istanbul.

It is almost impossible to obtain the age of the crossing person using only the camera recordings. Therefore, people crossing the street were divided into 4 classes as “children”, “young”, “middle aged” and “older”. 66 of the street crossings were performed by children ($M = 1.3574$, $SD = 0.47669$), 2.758 by young ($M = 1.3425$, $SD = 0.47873$), 1.830 by the middle aged ($M = 1.2803$, $SD = 0.46560$) and 436 by the older ($M = 1.1933$, $SD = 0.34234$) age groups. A one-way between subjects ANOVA was conducted to compare the effect of age on the crossing speed. There was a significant effect of age on the crossing speed at the $p<.05$ level for the four age groups $F(4.5094) = 12.719$, $p = 0.000$]. These results suggest that, as the people get older, their crossing speed significantly decreases.

Talking with the mobile phone during the crossing movement, carrying objects such as bags, sachets, etc. and walking around with animals are defined as distraction. Among 5.098 street crossings, 2.284 were conducted by the distracted people, while on the remaining 2.714, the crossing people were undistracted while crossing. There wasn’t any significant difference in the scores for distracted ($M = 1.2843$, $SD = 0.44371$) and undistracted ($M = 1.3282$, $SD = 0.48328$) conditions; $t(5096) = -3.329$, $p = 0.1317$. These results show that, in contrary to the popular social belief, distraction doesn’t have a significant effect on the crossing speed of pedestrians.

Only 12 crossings by the disabled people could be determined from the video recordings. The disabled people crossed significantly slower ($M = 0.8075$, $SD = 0.23332$) than the non-disabled people ($M = 1.3084$, $SD = 0.46551$); $t(5096) = 3.726$, $p = 0.000$. These results state that, the disability greatly reduces the crossing speed of the pedestrians.

On 3.728 of the 5.098 street crossings observed, people crossed alone while on the remaining 1.370 they have crossed in a group of at least 2 people. The people who crossed alone ($M = 1.3159$, $SD = 0.46965$) were significantly faster than people within a group ($M = 1.2075$, $SD = 0.34808$) conditions; $t(5096) = 7.786$, $p = 0.000$. These results show that, being in a group while crossing decreases the crossing speed.

Effect of the Timing Measures on the Pedestrian Crossing Speed

The time of the day and the days of the week were examined as the timing measures that may affect the pedestrian crossing speed.

Out of 5.098 crossings recorded, 1.820 were performed in the morning (M = 1.4212, SD = 0.44850), 966 at noon (M = 1.2708, SD = 0.43155) and the remaining 2.312 in the evening (M = 1.2327, SD = 0.47522) hours. There was a significant effect of the hour on the crossing speed at the $p< 0.05$ level for the three groups; F (3.5095) = 90.105, p = 0.000].

The days of the week were divided into two groups as weekdays and weekends. The 3.255 crossings between Friday afternoon and Sunday night were defined as the weekend crossings, while the remaining 1.843 were defined as the weekday crossings. There wasn't any significant difference in the scores for weekdays (M = 1.3036, SD = 0.50582) and weekends (M = 1.3137, SD = 0.38475) conditions; t (5096) = - 0.747, p = 0.455.

Effect of the Weather on the Pedestrian Crossing Speed

Temperature and the weather condition that may affect the pedestrian crossing speed were examined for their effect on the pedestrian crossing speed.

Air temperatures between 1 ºC and 32 ºC have been observed during the study period. A one-way between subjects ANOVA was conducted to compare the effect of the temperature on the crossing speed. Each temperature value has been defined as a separate group. There was a significant effect of the temperature on the crossing speed at the $p<.05$ level; F (4.5094) = 66.497, p = 0.000].

Weather condition was defined in 4 groups as “sunny”, “cloudy”, “rainy” and “snowy” in order to examine the effect of weather condition on the pedestrian crossing speed. Out of 5.098 crossings recorded, 3.088 were performed in the sunny (M = 1.2996 SD = 0.49987), 1.590 in cloudy (M = 1.3323, SD = 0.41450), 302 in rainy (M = 1.2823 SD = 0.40252) and the remaining 115 in the snowy (M = 1.2312, SD = 0.28871) weather. A one-way between subjects ANOVA was conducted to compare the effect of the weather condition on the crossing speed. There was a significant effect of the weather condition on the crossing speed at the $p< 0.05$ level for the four groups; F (4.5094) = 3.119, p = 0.025].

Effect of the Location on the Pedestrian Crossing Speed

Land use type is the only locational condition that was investigated for its effect on the pedestrian crossing speed. Land use was defined in 3 categories as; “educational”, “business/shopping” and “recreational”. Out of 5.098 crossings recorded, 243 were performed in the school areas (M = 1.5079, SD = 0.47663), 1.163 in the business/shopping districts (M = 1.2002, SD = 0.43956) and the remaining 3.692 in the recreational areas (M = 1.3278, SD = 0.46590). A one-way between subjects ANOVA was conducted to compare the effect of the location on the crossing speed. There was a significant effect of the location on the crossing speed at the $p< 0.05$ level for the four groups; F (4.5094) = 58.060, p = 0.000].

Effect of the Traffic Conditions on the Pedestrian Crossing Speed

Motor vehicle density, pedestrian density at the traffic light and the color of the traffic light when the crossing movement began were examined for their effect on the pedestrian crossing speed.

2.268 of the crossings were performed during the motor vehicle density was on low level (M = 1.3761, SD = 0.50797), 1.979 on medium level (M = 1.3179, SD = 0.2421) and 848 on high level (M = 1.0982, SD = 0.36960). A one-way between subjects ANOVA was conducted to compare the effect of the motor vehicle density on the crossing speed. There was a significant effect of weather status on the crossing speed at the $p<.05$ level for the three groups; F (3.5095) = 115.747, p = 0.000].

2.160 of the crossings were performed during pedestrian density at the traffic light was on low level (M = 1.3233, SD = 0.42250), 2.072 on medium level (M = 1.3739, SD = 0.52142) and 866 on high level (M = 1.1076, SD = 0.36071). A one-way between subjects ANOVA was conducted to compare the effect of the pedestrian density

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on the crossing speed. There was a significant effect of weather status on the crossing speed at the p<.05 level for the three groups; F (3.5095) = 106.219, p = 0.000].

758 of the crossings started when the traffic light was red for the pedestrians and the remaining 3.170 when the light was green. Remaining 1.171 crossing occurred on places without any traffic lights. There was a significant difference in the scores for crossings started when red (M = 1.4582, SD = 0.48475) and green (M = 1.3106, SD = 0.46030) light was on, conditions; t (3926) = 7.846, p = 0.000. These results show that, pedestrians cross significantly faster when they started crossing during the red phase of the pedestrian signal.

FUZZY LOGIC MODEL

In this study, a fuzzy logic model has been developed in MATLAB® software in order to estimate the pedestrian crossing speed with respect to the effective criteria. The input of the model consisted of the effective criteria (gender, age group, disability, time of the day, temperature, weather condition, land use, motor vehicle density, pedestrian density and the color of the traffic light at the start of the crossing) and the output of the model is the pedestrian crossing speed.

Gender of a person was defined as a single crisp number, 1 indicating males (since they crossed faster) and 0 indicating females. Although the age group could be defined as a fuzzy parameter, it was also defined as a single crisp number 1, 0.7, 0.3 and 0 indicating children, young, middle aged and older, respectively, since the exact age data could not be obtained from the camera recordings. Disability status of a person was defined as a single crisp number as well, 0 indicating people without disabilities while 1 indicating people with disabilities (since they crossed slower).

Similar to the age group, time of the day also could be defined as a fuzzy parameter. However, since instead of exact time of the day, only the period was recorded during the data collection phase, so it was also defined with a crisp number, 1 indicating crossings during morning, 0.5 during noon and 0 during evening hours.

Between the input parameters, only the temperature was defined in fuzzy numbers. Temperature was defined in 5 fuzzy sets as “very cold”, “cold”, “mild”, “warm” and “hot”. All of the sets were defined with triangular membership functions.

Land use type was also defined as a single crisp number, 1indicating school areas, 0.5 recreational areas and 0 business/shopping districts.

Motor vehicle and pedestrian densities were defined as a single crisp numbers, 1indicating middle, 0.5 low and 0 high densities. Color of the traffic light at the start of the crossing movement was also defined as a single crisp number, 1indicating red and 0 green colors.

The single output of the model, namely the pedestrian crossing speed was defined in fuzzy numbers. The pedestrian crossing speed was defined in 5 fuzzy sets as “very slow”, “slow”, and “moderate”, “fast and very fast”. All of the sets were defined with triangular membership functions.

An initial rule base was generated using the expertness of the researcher from 10 input and single output parameter. The rules defining the relation between input and output parameters are defined as:

$RULE_1$: IF **gender** is A(1) AND **age group** is B(1) AND **disability** is C(1) AND **time of the day** is D(1) AND **temperature** is E(1) AND **weather condition** is F(1) AND **land use** is G(1) AND **motor vehicle density** is H(1) AND **pedestrian density** is I(1) and **color of the traffic light** is J(1) THEN **pedestrian crossing speed** is K(…)
$RULE_2$: IF **gender** is A(2) AND **age group** is B(1) AND **disability** is C(1) AND **time of the day** is D(1) AND **temperature** is E(1) AND **weather condition** is F(1) AND **land use** is G(1) AND **motor vehicle density** is H(1) AND **pedestrian density** is I(1) and **color of the traffic light** is J(1) THEN **pedestrian crossing speed** is K(…)
Also

$RULE_n$: IF **gender** is A(2) AND **age group** is B(4) AND **disability** is C(2) AND **time of the day** is D(3) AND **temperature** is E(5) AND **weather condition** is F(4) AND **land use** is G(3) AND **motor vehicle density** is H(3) AND **pedestrian density** is I(3) and **color of the traffic light** is J(3) THEN **pedestrian crossing speed** is K(…)

Thus, n = 2 x 4 x 2 x 3 x 5 x 4 x 3 x 3 x 3 x 3 = 77.760 initial rules have been generated that estimates the pedestrian crossing speed. In order to calibrate the fuzzy logic model, a genetic algorithm that minimizes the Mean Square Error (MSE) of the outputs have been developed. Each gene of the chromosomes represented start, peak and end points of triangular membership functions. Hence, a single chromosome consisted of 3 x 5 (for calibration of temperature membership functions) + 3 x 5 (for calibration of crossing speed membership functions) = 30 genes. Each generation of the genetic algorithm was comprised of 200 individuals. Cross-over parameter, P(C) was selected as 1 and the mutation parameter P(M) was selected as 0.001. The genetic algorithm ran for 1000 iterations before termination and best two chromosomes of each iteration were protected in the following one. Upon termination of the genetic algorithm, a local search method that searches for better solutions around the best solution obtained is applied. In this method, the value of each gene of the best solution is changed with small margins to check whether MSE value decreases or not. If a lower MSE value is obtained, the search continues, or else the value of the next gene is changed. If none of the 30 genes provides a better solution, the local search is finalized.

RESULTS AND DISCUSSION

The result of the fuzzy logic model is given as a scatter diagram in Figure 1. The values on the horizontal axis show the observed values, while the values on the horizontal axis show the results obtained from the fuzzy logic model. The determination coefficient (R^2 value) of the model was calculated as 0.4533. This relatively low value indicates that the fuzzy logic model does not perform very well on estimating the pedestrian crossing speed. This may be due to various reasons. First of all, the criteria taken into account can be insufficient/inadequate to mimic the street crossing behavior/speed of the pedestrians. Investigation of the effect of some other parameters and including them as an input parameter into the model may greatly improve the estimation performance of the fuzzy logic model. Moreover, defining criteria such as age group, time of the day, motor vehicle and pedestrian densities as fuzzy numbers can also improve the estimation performance of the model.

Another point that has to be taken into account is that the human behavior is rather stochastic than deterministic. Thus, behavior of two similar people may differ greatly and also the behavior of the same person may change from time to time, according to his/her mood. Therefore, no matter how strong a model is established, it should not be expected to reflect perfectly the pedestrian crossing behavior/speed. However, a high performance developed model will serve as an important guide in the design and optimization of transportation facilities such as the crosswalks and the signal timings of the traffic lights.

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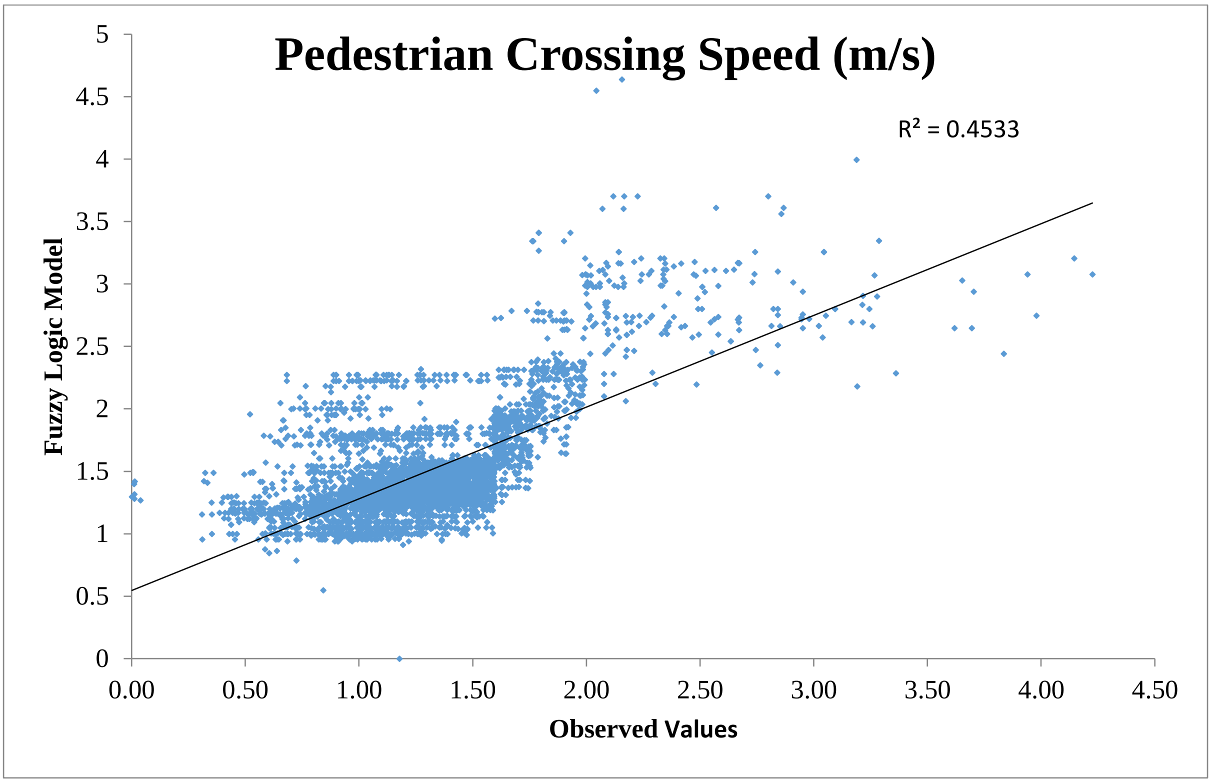

Figure 1. Scatter diagram of pedestrian crossing speed

CONCLUSION

Pedestrian crossing speed is an important factor on the design of the type and the size of the crosswalks. It also affects the signal timings of the traffic lights. People in different countries may cross the streets using different average crossing speeds. So that the reginal conditions have to be researched in order to make appropriate designs. Gender, age group, disability, time of the day, temperature, weather condition, land use, motor vehicle density, pedestrian density and the color of the traffic light at the start of the crossing found to be effective on the pedestrian crossing speed in Istanbul. Developed fuzzy logic model can reproduce the behavior of pedestrians with a R^2 value of 0.4533, which can further be improved by taking other factors into account. A generated model can be used as an assistant on real time traffic control systems as well.

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