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Modeling of Pedestrians Crossing at Signalized Intersections

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Abstract: In Saudi Arabia, pedestrian violation is a major cause of pedestrian traffic accidents. The main objective of this study is to enhance traffic signals utilization through organizing and managing pedestrian's crosswalks at signalized intersections. The study was conducted at two signalized intersections on King Saud Road in Tabuk city. Field measurements signal timing, and pedestrian's volume was counted during the peak hour. The average arrival rate was calculated to be 282 pedestrians/ hour, and average service rate was 156 pedestrians/ hour. The study proposed a model connecting between crossing pedestrians and signal timing based on actual field measurements at the studied area. The study results indicated that average pedestrian's waiting time at the two intersections is 26.5 and 25 seconds respectively. The present study found that the model can be used to design the pedestrian signal, since green time is the main element of model output.

Keywords: Pedestrian Behavior, Crosswalk, Signal Timing, Queuing Theory, Model Notation

1. Introduction

An interaction between pedestrian and vehicles usually occurred due to pedestrian illegal crossing. In Tabuk City, a lot of pedestrians cross the roadway randomly. Traffic accidents involving pedestrians have become a major safety problem all over the world. Several tools were used to protect pedestrians and to help them cross roads safely and comfortably. Crossing pedestrian signal at intersection is one of these tools. Pedestrian signals help pedestrians cross the road with traffic lights. A pedestrian facing a walk signal may cross the road in the direction of the signal. While crossing, pedestrians have the right-of-way over all vehicles. There are two common countdown signals: timer signal and call button signal. Such signal provides safe crossing for pedestrian at intersections, by counting pedestrians frequency and calculating the necessary timing.

The study aimed to manage pedestrian's crosswalks and to enhance traffic signals utilization. The study developed mathematical model to describe pedestrian behavior at and during crossing based on actual field measurements at crosswalks in two signalized intersections. The study was conducted on King Saud Road (one way street) in Tabuk city. The two signalized intersections namely: Eddy intersection and Enjaz Intersection were chosen to conduct the study as shown in figure 1.

Figure 1. *Study Area.*

2. Literature Review

Historically, some pedestrian studies were conducted in several countries, and each study different from the other according to several factors such as pedestrian crossing volume, pedestrian crossing behavior, vehicles traffic volume, and crosswalk dimensions. The study of Issa concluded that the main reason of traffic accidents in Saudi Arabia related to inadequacies of supervision by the law enforcement agents [1]. A local study found that 76% of total accidents are related to human errors [2].

Marisa and Vedagiri analyzed the crossing behavior of pedestrians under mixed traffic conditions and identified the influencing factors based on statistical tests. The study determined the design crossing speed for old and adult pedestrians at 0.95 m/s and 1.12 m/s respectively [3]. The study of Xin ZHANG investigated the effects of pedestrian green time, crosswalk length and pedestrian crossing direction on pedestrian walking speed at signalized crosswalk. The study conducted a comparison of pedestrian speed models at pedestrian green time and pedestrian flashing green time (PFG) demonstrates that pedestrian walking speeds at PFG are higher and more variable [4].

The study of Guo investigated the relationship between waiting duration and pedestrian violation. Results indicated that about 10 percent of pedestrians were at high risk of violation to cross the street. About half of pedestrians would still obey the traffic rules even after waiting for 50 s by the street [5]. Abaza developed a mathematical model to estimate the actual green time for pedestrian signal for CBD areas [6]. According to the European code for crosswalks crosswalks shall be solid white not less than 0.15 m (6 in) nor greater than 0.6 m (24 in) in width and not less than 1.8 m (71 in) nor greater than 3.0 m (120 in) in length [7].

From TABC, it was indicated that more than 50% of pedestrian crashes occurred at signalized intersections in China [8], with 24.62% of all traffic fatalities were for pedestrians compared to 12.1% in U.S [9]. Zhu-Ping explored different pedestrian behaviors at signalized intersections in China manually in the field study, and distributed a questionnaire to the same participant to acquire their attitude and preference indicators. Results showed that gender, age, arrival time, the presence of oncoming cars, and crosswalk length are the most important factors for violation [10]. Srinivas, report focused on the crossing behavior of pedestrians at traffic signalized intersections. On-site surveys were conducted to obtain information on the behavior using a video recording technique [11].

3. Data Collection

The data collected for this study includes: field geometric measurements, traffic signal timing, and pedestrian volume count on crosswalks. Field measurements were conducted to determine number of channels and time spends in the system. These measurements include crosswalk length and width. The crosswalk width and length was about 2.5m and 10.5m respectively. To determine the number of channels, crosswalk width is divided into 0.85m sectors which assumed to represent the length of walking buffer for pedestrian [12].

A fixed signal operation was found for the north approach for Eddy intersection (cycle length=135 seconds) and for Enjaz intersection (cycle length=110 seconds) as shown in table 1 below.

Table 1. *Traffic signal timing.*

Intersection Name	Vehicles				Pedestrians	
	Green	Red	Yellow	All Red	Green	Red
Eddy	41 Sec	90 Sec	3 Sec	1 sec	84 Sec	51 Sec
Enjaz	37 Sec	69 Sec	3 Sec	1 sec	62 Sec	48 Sec

The pedestrian count was conducted at the two intersections in March 2017; during pedestrian peak hour which is between 8 to 9 pm. Number of arrived pedestrians during each pedestrian's red signals was counted at this hour. Figure 2 below identifies number of pedestrian's arrival during the peak hour in each pedestrian red interval.

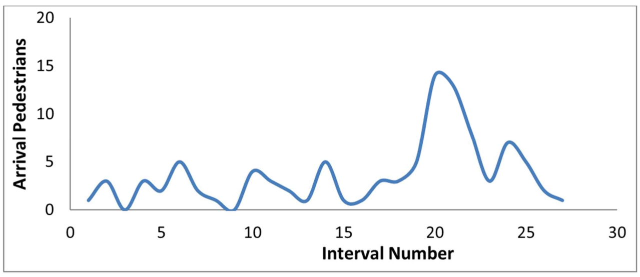

Figure 2. *Pedestrian arrival distributions at Eddy crosswalk.*

Number of pedestrian's service during the peak hour in each pedestrian green interval is shown in figure 3.

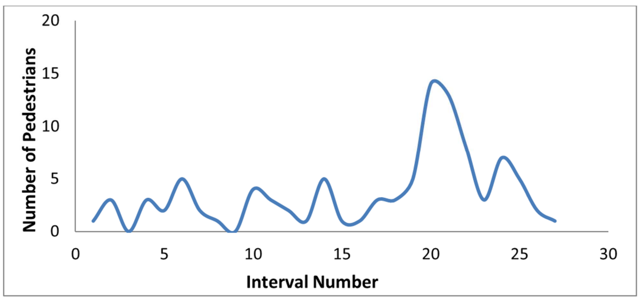

Figure 3. *Pedestrian service distributions at Eddy crosswalk.*

Counts and above signal timing were used to calculate average arrival rate (λ), defined as

$$\lambda = (\text{No. of pedestrians*3600})/(\text{pedestrian red interval}) \quad (1)$$

Calculated pedestrian arrival rates are summarized in table 2 below.

Table 2. *Calculated Pedestrian Arrival Rate at Eddy Crosswalk.*

Interval #	No of Pedestrians	Arrival Rate (Ped/Hr)	Interval #	No of Pedestrians	Arrival Rate (Ped/Hr)
1	1	71	15	1	71
2	3	212	16	1	71
3	0	0	17	3	212
4	3	212	18	3	212
5	2	141	19	5	353
6	5	353	20	19	1341
7	2	141	21	17	1200
8	1	71	22	8	565
9	0	0	23	3	212
10	4	282	24	8	565
11	3	212	25	5	353
12	2	141	26	2	141
13	1	71	27	1	71
14	5	353			
Average Arrival Rate (Ped/Hr)		282			

Interval #=3600/cycle length

Service rate (μ) was found using the equation:

$$(\mu) = (\text{No. of pedestrians*3600})/(\text{pedestrian green interval}) \quad (2)$$

Calculated pedestrian service rates are summarized in table 3 below. It is important to mention that since this street is one way road, the green time is large enough to allow almost all pedestrian to cross during green interval.

Table 3. *Calculated Pedestrian Service Rate at Eddy Crosswalk.*

Interval #	No of Pedestrians	Service Rate (Ped/Hr)	Interval #	No of Pedestrians	Service Rate (Ped/Hr)
1	1	43	15	1	43
2	3	129	16	1	43
3	0	0	17	3	129
4	3	129	18	3	129
5	2	86	19	5	214
6	5	214	20	14	600
7	2	86	21	13	557
8	1	43	22	8	343
9	0	0	23	3	129
10	4	171	24	7	300
11	3	129	25	5	214
12	2	86	26	2	86
13	1	43	27	1	43
14	5	214			
Average Service Rate (Ped/Hr)		156			

The same is done for Enjaz crosswalk with (352ped/hr) average arrival rate and (274ped/hr) average service rate.

4. Mathematical Model Coding

The queuing theory was utilized to model this process. Queuing theory models are expressed in a standard notation and use a suite of parameters in the model formulae. A queuing model is defined in terms of the five characteristics: arrival rate, service rate, number of (parallel services) channels, restriction on system capacity, and queue discipline type [13]. Since pedestrian arrival at crosswalk and departure from it takes the form of a poison distribution, and the crosswalk is divided into more than one channel, M/M/C model may be applicable. The buffer zone is assumed to equals to 0.75m^2. The maximum number of channels in the system is estimated as $C=\left|\frac{w}{\sqrt{0.75}}\right|$ (where w equals to the existing crosswalk's length=2.5m). Applying the steady state conditions at any point, the expected rate of flow in that point = expected rate of flow out from the same point. The following equations may be applied [14].

$$\rho = \left(\frac{\lambda}{\mu}\right) \Rightarrow P_0 = \left[\sum_{n=0}^{c-1} \frac{\rho^n}{n!} + \frac{\rho^c}{c!} \times \left(\frac{1}{1-\frac{\rho}{c}}\right)\right]^{-1} \quad (3)$$

$$L_q = \left(\frac{\rho^{c+1}}{(c-1)! \times (c-\rho)^2}\right) \times p_0 \Rightarrow L_s = L_q + \rho \quad (4)$$

$$W_q = \frac{L_q}{\lambda} \Rightarrow W_s = W_q + \frac{1}{\mu} \quad (5)$$

Where:

Po : Probability of having no customers in the System

L_s : Expected number of customers in the System

L_q : Expected number of customers in the Queue

W_s : Average waiting time in the System

W_q : Average waiting time in the Queue

Applying the above equations to find W_s at Eddy intersection, this represents pedestrian green time.

$$\lambda = 282\text{ped/hr},\ \mu = 156\text{ped/hr} \Rightarrow \rho = 1.8$$

$$p_0 = 0.074 \Rightarrow L_q = 0.27 \Rightarrow W_q = 0.00096\text{hr} \Rightarrow W_s = 0.0074\text{hr} = 26.5\text{sec}$$

Same is done at Enjaz intersection with W_s=25 sec.

5. Conclusions

Modeling pedestrian behavior is usually not too difficult to obtain in lightly developed areas compare to urban areas with limited space. Pedestrian becomes under tension to pass the road safely in congested areas. This study proposed a mathematical model based on field measurements, signal timing, and pedestrian's volume at two signalized intersections in Tabuk City. The average arrival rate was calculated to be 282 pedestrians/ hour, and average service rate was 156 pedestrians/ hour. The developed model is based on queuing theory, "first-come-first-served" queues. Average pedestrian's waiting time at the two studied intersections is 26.5 and 25 seconds respectively. Based on these results, pedestrian signal can be designed since green time (W_s) is the main element of model output.

6. Recommendations

As a result of this study, the following recommendations were depicted: The model can be applicable in other similar intersections and other urban areas in general. Further analysis of the potential applicability of a model in rural (non-congested) areas, and the possibility of the inclusion of disabled pedestrian in the model is needed. It is also recommended to strengthen pedestrians' knowledge of obeying the rules, and the pedestrian crossing facilities should be carefully designed.

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