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**Research Article**

# DETERMINATION OF PEDESTRIAN ARRIVAL HEADWAY DISTRIBUTION AT SIGNALIZED CROSSWALKS IN ISTANBUL

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**ABSTRACT**

Pedestrian crossing characteristics are important for the design of signalized urban intersections and signalized crossings. There are many different factors that affect pedestrians flow at these locations such as cycle and green times, width of the roads, time headway of vehicles and pedestrians. The optimum cycle time is frequently calculated by minimizing the user delays at an intersection, while users are defined as vehicles and pedestrians. Through statistical distribution models, prediction for crossing opportunity with minimal amount of information is possible. Therefore, statistical distributions with a certain degree of randomness can be used to model vehicle and pedestrian flow, effectively. If the delay or average waiting time is extremely long, the pedestrians' likelihood of violating the signal, increases.
The aim of this study is to determine the distribution of pedestrian arrival headways at signalized intersections and calculate the pedestrian average waiting time (delay) which affects the green time. Field study was conducted at six intersections where pedestrian flows were low, moderate and high in Istanbul. Chi-squared and Kolmogorov-Smirnov tests were used to investigate and determine the distribution of pedestrians' arrival headways. It is found that Gamma distribution is the best-fitted distribution for pedestrian arrival headway.
**Keywords:** Arrival headway distribution, pedestrian crossing, signalized intersection.

## 1. INTRODUCTION

Walking is one of the transportation ways, which can make a connection between an individual, the environment, and the society when other means of transportation specially motorized vehicles are not available [1-2]. Better planning for pedestrians helps to provide better linkage among various transport modes, enhance land use activities, improve pedestrian circulation, quality of walking environments, and minimize conflict between pedestrians and vehicles at the signalized crosswalks. Therefore, understanding pedestrian walking characteristics, behavior and pedestrian needs are of prime importance in the study of planning and design of the pedestrian facilities. Among various pedestrian facilities, signalized crosswalks are one of the most complex facilities, with high risk of accident for pedestrians in congested urban areas, since

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pedestrians and vehicles share the same road space, in accordance with the signal cycles. The complexity of the traffic signals often creates problems since the provision and allocation of crossing time for pedestrians is usually apportioned from conflicting vehicular traffic flows [3].

Many different factors can affect pedestrians flow at signalized intersections [4-5]. The time headway, one of these factors, between vehicles and pedestrians at intersections is similarly an important flow characteristic that affects safety. Through statistical distribution models, determination of these time headways prediction for crossing opportunity is possible with minimal amount of information. Therefore, statistical distributions with a certain degree of randomness can be used to model traffic and pedestrian flow, effectively. Ali and Najafi [6] studied in Karachi, Pakistan, the determination of a low-cost methodology for the selection of proper pedestrian crossing facilities by anticipating pedestrian delays. They formed a model for the arrival of pedestrians at crosswalks by using Gamma (Pearson Type III) distribution. Wei et al. [7] developed the method to estimate the vehicular delay with the yielding behavior at unsignalized crosswalks; while they assumed pedestrian arrival headways follow the shifted negative exponential distribution in China. Akçelik [8] investigated the pedestrians' arrival headways in Australia and found that pedestrians' arrival headways follow the negative exponential distribution model.

In the literature, a lot of attention has been paid to the researches for pedestrian's behavior at signalized and unsignalized crosswalks; however, there are only a few studies on the investigation of pedestrian waiting time distribution[9-10]. Waiting time delay is an important measure to design signal timing plan and evaluate the performance of signalized intersections. The pedestrians' likelihood of violating the signal changes according to the cycle time. In fact, if the average delay is higher than 60 sec, then the likelihood of non-compliance is extremely high [11]. Li et al. [5] conducted a field study in China and estimated the pedestrians waiting time delay at signalized intersections through the 13 crosswalks at nine intersections. The measured average pedestrians waiting time was equal to 12.3 sec. Malinovsky at al. [12] measured the pedestrians waiting time at three signalized crosswalks in Washington and found 1.4, 5.0 and 6.6 sec, respectively. The shortest value was partly due to the long pedestrian phase. Most pedestrians were likely to arrive at the crosswalk in green signal indication, resulting a prompt crossing without waiting. Nevertheless, several extreme values obtained at other crosswalks, 30% of pedestrians waited over 20 sec at the second pedestrian crossing, and 12.5% of pedestrians waited for 30 sec and third pedestrian crossing.

The purpose of this study is to determine the distribution of pedestrian arrival headways at signalized crosswalks and calculate the average pedestrians waiting time. The determination of arrival headway distribution of pedestrians will provide more realistic values for pedestrian delay, which is an entry of cycle time calculation.

## 2. DATA COLLECTION

In order to collect data, field study was conducted at six different Pedestrian Crosswalks (PC) in Istanbul, during October 2016. Crosswalks are selected based on the crossing pedestrian flow rates, such as low (0-400 ped/h), moderate (400-1000 ped/h) and high (over 1000 ped/h). The properties of surveyed crosswalks are given in Table 1. The ID number is a unique number of existent traffic light at each PC, given by Istanbul Metropolitan Municipality, through the city. Figure 1 shows the two surveyed pedestrian crosswalks for low (at PC 1) and high (at PC 6) flow rates, respectively.

**Table 1.** Properties of Surveyed Pedestrian Crosswalks

| Pedestrian Flow Rate | Pedestrian Crosswalk | ID Number | Type of Intersection | Intersected Roads |
|---|---|---|---|---|
| Low | PC1 | 2327 | Midblock | Büyükdere Av. |
| | PC 2 | 2279 | 3-Leg | Aytar Av. – Aydın St. |
| Moderate | PC 3 | 2236 | Midblock | Halaskargazi Av. |
| | PC4 | 2448 | 3-Leg | Eski Büyükdere Av. – Dereboyu Av. |
| High | PC 5 | 4500 | 4-Leg | Kemeraltı Av. – Tersane Av. |
| | PC 6 | 2228 | 4-Leg | Mecidiyeköy Yolu Av. – Lati Lokum St. |


**(a) PC 1**


**(b) PC 6**

**Figure 1.** Surveyed Pedestrian Crosswalks

All data are gathered in weekdays, off-peak hours by two observers simultaneously located at both sides of the crosswalk and equipped with stopwatches. The observers measured the arrival headways of consecutive pedestrians, which arrive in their considered waiting area as given in Figure 2. Meanwhile the time of light cycles are recorded.

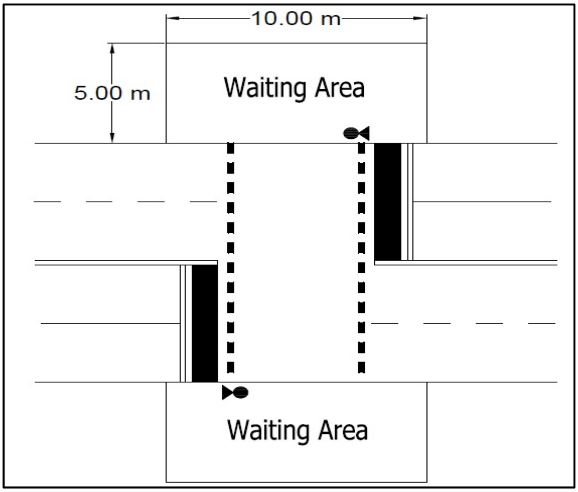


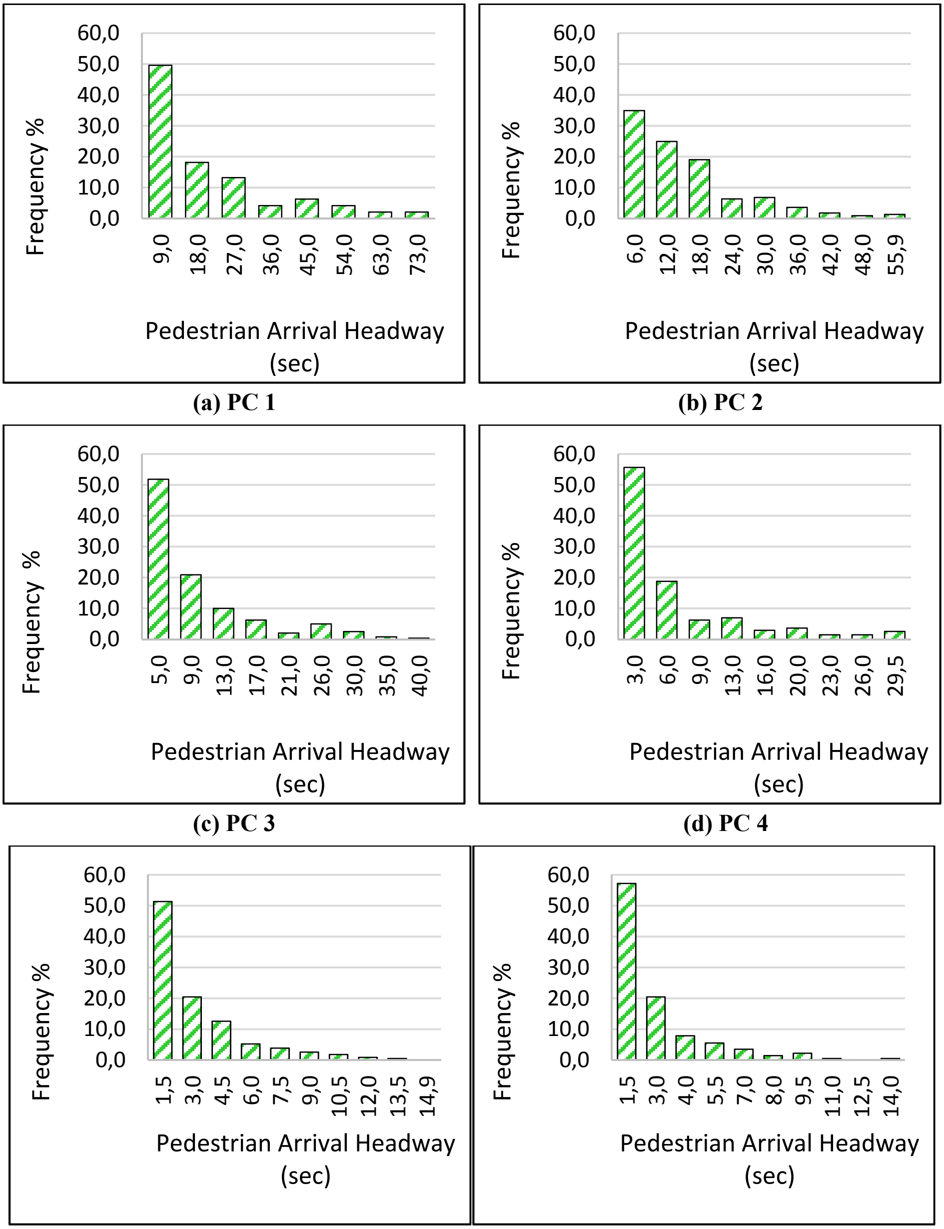

**Figure 2.** Considered Waiting Area

## 3. DATA ANALYSIS

The statistics of gathered data at each intersection are given in Table 2, where the mean value of pedestrian arrival headways at crosswalks with low flow rate is 13.3 sec, which is almost 6 times more than the mean value of intersections with high flow rate (2.3 sec). It means that the effect of pedestrian arrival headways in high flow intersections is totally different from the intersection with low pedestrian flow rate, which will be evaluated statistically in the next parts of the study. The histograms of pedestrian arrival headways at all surveyed crosswalks are given in Figure 3.

**Table 2.** Statistics of Pedestrians Arrival Headways (sec)

| Pedestrian Flow Rate | Count | Intersection | Mean | Sta. Dev. | Skewness | Kurtosis | Max | Min |
|---|---|---|---|---|---|---|---|---|
| Low | 155 | PC 1 | 14.7 | 16.7 | 1.6 | 2.0 | 73.0 | 0.9 |
| | 230 | PC 2 | 11.9 | 10.9 | 1.5 | 2.2 | 55.9 | 0.9 |
| Moderate | 253 | PC 3 | 6.9 | 7.5 | 1.8 | 3.1 | 40.0 | 0.5 |
| | 274 | PC 4 | 5.5 | 6.5 | 2.0 | 3.6 | 29.5 | 0.3 |
| High | 558 | PC 5 | 2.4 | 2.6 | 1.8 | 3.2 | 14.9 | 0.2 |
| | 545 | PC 6 | 2.1 | 2.3 | 2.1 | 5.0 | 14.0 | 0.2 |




**(a) PC 1** **(b) PC 2**

**(c) PC 3** **(d) PC 4**

**(e) PC 5** **(f) PC 6**

**Figure 3.** Histograms of Pedestrian Arrival Headways

Collected data for each crosswalk are investigated with Chi-squared ($\chi^2$) and Kolmogorov-Smirnov (K-S) tests to determine the statistical distributions of pedestrian arrival headways with the help of "Mathwave" software. Several probability distribution functions such as Normal distribution, Gamma distribution, Gumbel distribution, Negative Exponential distribution, Weibull distribution, Frechet distribution and etc. are analyzed with the mentioned goodness-of-fit tests. Table 3 shows the results of $\chi^2$ and K-S tests for low, moderate and high pedestrian flow rates at crosswalks.

**Table 3.** Distributions of Pedestrians Arrival Headways at Crosswalks

| Pedestrian Flow Rate | Intersection | Distribution | | Chi-squared | | | Kolmogorov-Smirnov | |
|---|---|---|---|---|---|---|---|---|
| | | | | df | Critic. | Stat. | Critic. | Stat. |
| Low | PC 1 | 1 | Gamma | 5 | 14.07 | 3.95 | 0.11 | 0.06 |
| | | 2 | Log-normal | 5 | 14.07 | 7.83 | 0.11 | 0.07 |
| | | 3 | Weibull | 5 | 14.07 | 6.20 | 0.11 | 0.06 |
| | PC 2 | 1 | Gamma | 6 | 14.07 | 4.58 | 0.09 | 0.04 |
| | | 2 | Log-normal | 6 | 14.07 | 8.94 | 0.09 | 0.08 |
| | | 3 | Weibull | 6 | 14.07 | 7.95 | 0.09 | 0.04 |
| Moderate | PC 3 | 1 | Gamma | 6 | 14.07 | 7.93 | 0.09 | 0.05 |
| | | 2 | Log-normal | 6 | 14.07 | 10.36 | 0.09 | 0.07 |
| | | 3 | Weibull | 6 | 14.07 | 6.09 | 0.09 | 0.05 |
| | PC 4 | 1 | Gamma | 5 | 14.07 | 3.72 | 0.10 | 0.06 |
| | | 2 | Log-normal | 5 | 14.07 | 5.57 | 0.10 | 0.06 |
| | | 3 | Weibull | 5 | 14.07 | 8.98 | 0.10 | 0.07 |
| High | PC 5 | 1 | Gamma | 7 | 16.92 | 10.42 | 0.06 | 0.05 |
| | | 2 | Pearson 6 | 7 | 16.92 | 18.28 | 0.06 | 0.05 |
| | | 3 | Weibull | 7 | 16.92 | 19.54 | 0.06 | 0.05 |
| | PC 6 | 1 | Gamma | 7 | 16.92 | 12.25 | 0.06 | 0.09 |
| | | 2 | Pearson 6 | 7 | 16.92 | 20.25 | 0.06 | 0.05 |
| | | 3 | Weibull | 7 | 16.92 | 16.13 | 0.06 | 0.05 |

The first three best fitted distribution models for all surveyed crosswalks at the 5% level of significance are tabulated; as it can be seen in Table 3, the Gamma (Pearson type III) distribution function is commonly the best fitted between all data sets. The probability density function of Gamma distribution is given by Eq. 1.

$$f(x) = \frac{x^{\alpha-1}e^{-\frac{x}{\beta}}}{\Gamma(\alpha)\beta^{\alpha}} \tag{1}$$

Where:

α and β: Gamma distribution parameters

$\Gamma(\alpha)$: Gamma function

The Gamma distribution parameters at each PC are given in Table 4.

**Table 4.** Gamma Distribution Parameters of Crosswalks

| Parameter | PC 1 | PC 2 | PC 3 | PC 4 | PC 5 | PC 6 |
|---|---|---|---|---|---|---|
| α | 0.77 | 1.20 | 0.86 | 0.72 | 0.99 | 0.89 |
| β | 15.10 | 9.92 | 8.10 | 7.60 | 2.20 | 2.06 |

As it can be seen in Table 3, Log-normal and Weibull distribution models are common between low and moderate flow rate crosswalks, while at the high flow rate crosswalks, Pearson 6 distribution model is confirmed instead of Log-normal distribution model.

After the determination of pedestrian arrival headways probability distribution function for each PC separately, the statistical differences between crosswalks with similar pedestrian flow rates are investigated with the help of Mann-Whitney U test, which is a powerful test when the data sets are not normally distributed. The Mann-Whitney U test is a nonparametric test of the null hypothesis that two samples come from the same population against an alternative hypothesis that two samples are from the different populations. The results of Mann-Whitney U test at the 5% level of significance for each pair of crosswalks are shown in Table 5. Since $Z_{sta}$ are smaller than $Z_{cri}$, the null hypotheses are failed to reject; that means the surveyed pedestrian crosswalks for similar flow rate are from the same population with the same characteristics.

**Table 5.** Results of Mann-Whitney U Test of Each Flow Rate

| Pedestrian Flow Rate | Intersection | $Z_{cri}$ | $Z_{sta}$ |
|---|---|---|---|
| Low | PC 1 | ±1.96 | -0.22 |
| | PC 2 | | |
| Moderate | PC 3 | ±1.96 | 1.78 |
| | PC 4 | | |
| High | PC 5 | ±1.96 | -0.65 |
| | PC 6 | | |

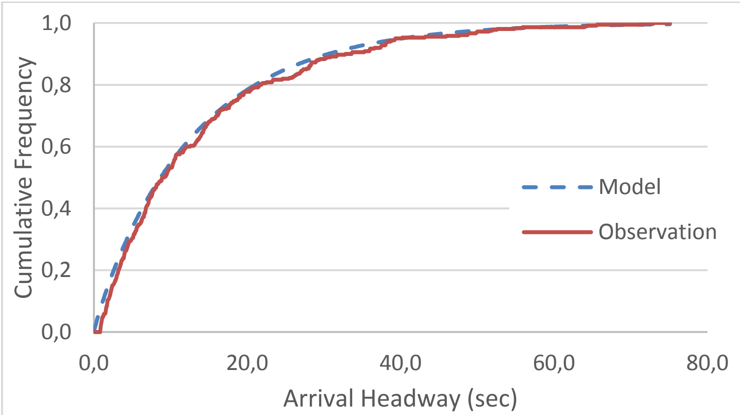
In order to determine the statistical differences between crosswalks with different pedestrian flow rates, Kruskal-Wallis H test was conducted. Kruskal-Wallis H test is a rank-based nonparametric hypothesis test that can be used to determine if there are statistically significant differences between two or more groups of data. At the 5% level of significance, the critical value of Kruskal-Wallis H test for three different groups of data is equal to 5.99, while the calculated statistical value is equal to 154.4; that means at least one data group is from different populations.

Accordingly, it is determined that the gathering of data is only possible when the pedestrian flow rates are similar. The distribution of pedestrian arrival headways is determined for three different pedestrian flow rates, by combining the data of "PC 1 and PC 2", "PC 3 and PC 4", and "PC 5 and PC 6", similar to disaggregate data. The best-fitted distribution is determined as Gamma distribution where its parameters are given in Table 6.

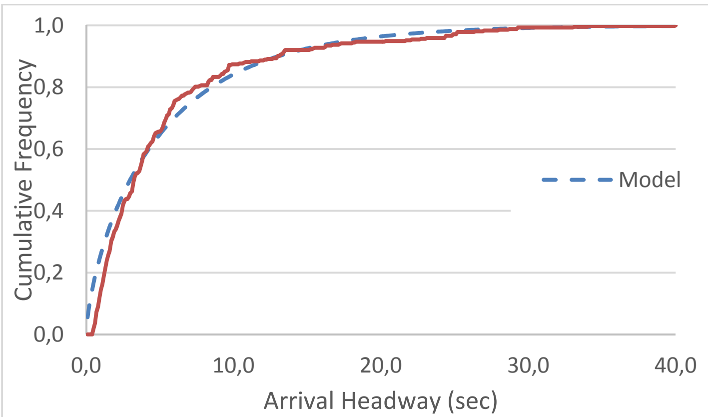
**Table 6.** Gamma Distribution Parameters of Different Pedestrian Flow Rates

| Parameter | Pedestrian Flow Rate | | |
|---|---|---|---|
| | Low | Moderate | High |
| α | 0.92 | 0.69 | 0.89 |
| β | 14.15 | 7.51 | 2.40 |

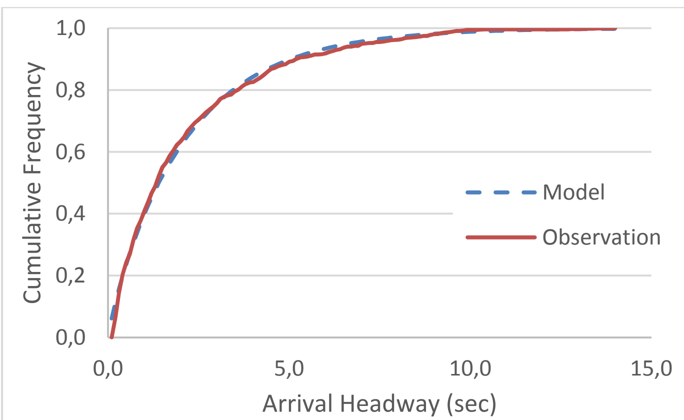
The cumulative distribution function of fitted Gamma distribution and the ogive of aggregated data are given in Figure 4. The probability density function of fitted Gamma distribution and frequency diagrams of aggregated data are given in Figure 5.




(a) Low Flow Rate

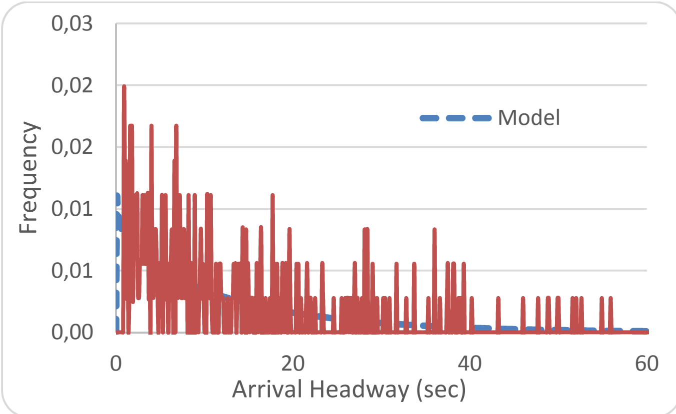



(b) Medium Flow Rate

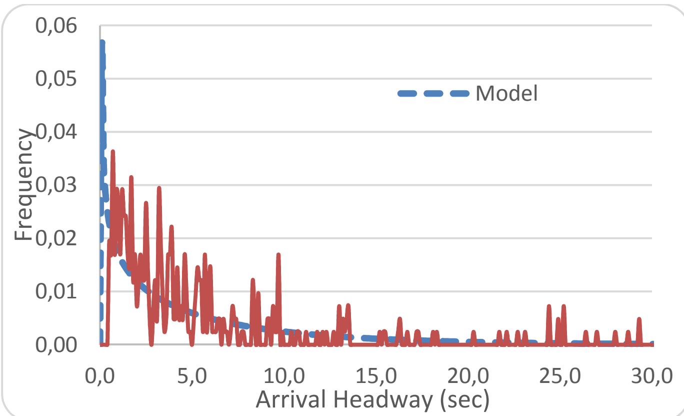



(c) High Flow Rate

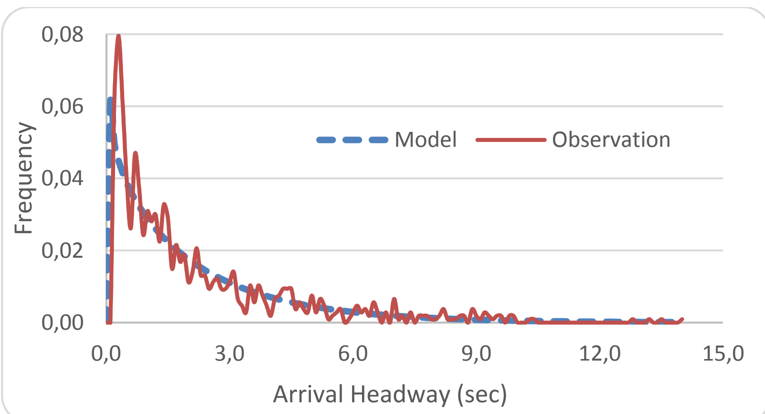
**Figure 4.** Cumulative Distribution Function of Gamma Distribution and Ogive of Aggregated Data




(a) Low Flow Rate




(b) Medium Flow Rate




(c) High Flow Rate

**Figure 5.** Probability Density Function of Gamma Distribution and Frequency Diagram of Aggregated Data

## 4. PEDESTRIAN WAITING TIME (DELAY)

The most commonly used pedestrian delay model at signalized intersections is given in Eq. 2 (TRB, 2010).

$$D = \frac{(C-G)^2}{2C} \tag{2}$$

Where $D$ is, the average pedestrian waiting time delay (sec), $C$ is the cycle length (sec) and $G$ is green time (sec). The model is developed considering assumptions such as "uniform arrival rate of pedestrian", "noncompliance pedestrian flow" and "fixed cycle length". The time series of pedestrian arrival flow rate at surveyed crosswalks with 60 sec intervals for 10 min, are given in Figure 5. As can be seen in Figure 5, the pedestrian arrival flow rate at all surveyed crosswalks are non-uniform.

The cycle time properties of observed pedestrian crosswalks are given in Table 7.

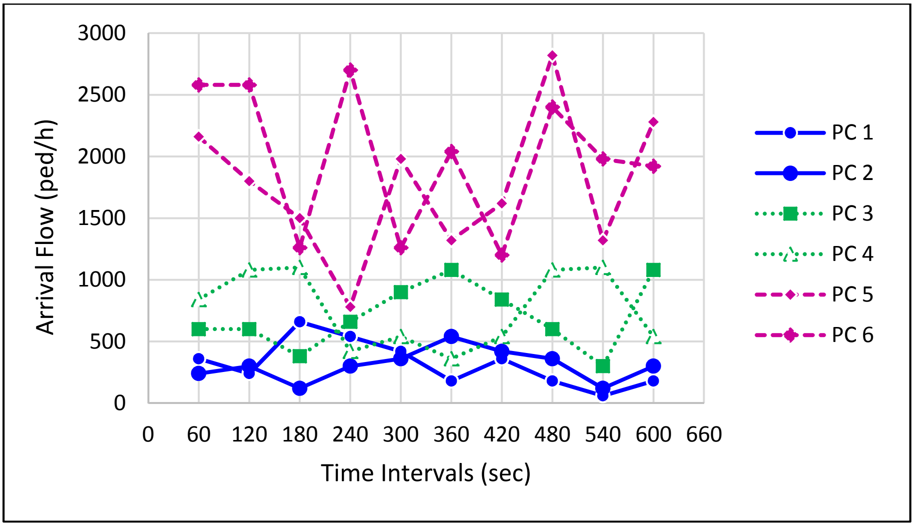



**Figure 5.** Pedestrians Arrival Rates

**Table 7.** Cycle Time Properties of Observed Crosswalks

| Intersection | Cycle Type | Cycle Time (sec) | |
|---|---|---|---|
| | | Red Time for Pedestrian | Green Time for Pedestrian |
| PC 1 | Variable | 155 - 165 | 15 - 30 |
| PC 2 | Variable | 60 - 75 | 10 - 20 |
| PC 3 | Variable | 60 - 95 | 15 - 30 |
| PC 4 | Fixed | 70 | 15 |
| PC 5 | Variable | 55 - 70 | 20 - 30 |
| PC 6 | Fixed | 105 | 25 |

In spite of the non-uniform pedestrian arrival rates and variable cycle times, the waiting times are calculated with the help of Eq. 2, and are compared with the measured values. The measured and calculated waiting times are presented in Table 8. In the case of variable cycle or red or green times, “the calculated waiting times” in Table 8 are determined by weighted average, with respect to these variable times.

**Table 8.** Measured and Calculated Pedestrian Waiting Delays

| Intersection | Waiting Time (sec) | | Error % |
|---|---|---|---|
| | Measured | Calculated | |
| PC 1 | 79.8 | 71.2 | 12.1 |
| PC 2 | 36.7 | 30.6 | 19.9 |
| PC 3 | 40.7 | 31.8 | 27.9 |
| PC 4 | 35.8 | 28.8 | 24.3 |
| PC 5 | 31.8 | 22.5 | 41.3 |
| PC 6 | 44.6 | 42.4 | 5.1 |

Eq. 2 underestimates the waiting times for all crosswalks. As the assumptions of Eq. 2 are not met, the presence of these errors is usual.

It is noted that at the crosswalks with low and moderate pedestrian flow rates, most of the pedestrians do not respect the red light and tend to cross illegally without waiting for the green light, however, at intersections with high pedestrian flow rate, due to the high vehicle flow rate, they don’t have an opportunity to cross in the red phase and have to wait for green phase.

## 5. CONCLUSION

This study attempts to determine the pedestrian arrival headways distribution with different pedestrian flow rate at signalized crosswalks.

The best-fitted probability distribution for all observed pedestrian crossing is determined as Gamma distribution. Log-normal and Weibull distributions are second and third probability distributions for PC with low and moderate pedestrian flow rates. On the other hand, for PC with high pedestrian flow rates, the second and the third best fitted distributions are Pearson 6 and Weibull.

The measured average waiting time delay at PC 1, 2, 3, 4, 5 and 6 are equal to 79.8, 36.7, 40.7, 35.8, 31.8 and 44.6 sec, respectively. According to Highway Capacity Manual [13], level of service of pedestrians are determined as F, D, E, D, D and E, correspondingly.

The average waiting times are similarly calculated by HCM’s suggested formula for all PC, while 5 to 40% relative errors are determined. HCM’s formula underestimates waiting times for all analyzed crosswalks.

The pedestrian arrival distribution must be taken into account by calculating cycle times. High waiting time leads pedestrians to cross illegally (in pedestrian red phase) by increasing accident rate.

In the future studies, the sample size can be increased in order to increase the reliability of the analysis. The effect of location, where the pedestrian flow rates change dramatically in a day, such as public transportation terminals, stops, shopping malls, schools, and hospital can be analyzed. In addition, the effects of weather condition on pedestrian arrival headway distribution can be studied. Moreover, HCM pedestrian delay formula can be modified in order to respond to non-uniform pedestrians arrival.

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