# A STUDY FOR PEDESTRIAN SIGNAL TIMING IN KOREA

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abstract: Proper pedestrian signal timing will reduce traffic accidents at intersections. The main purpose of the research is to estimate pedestrian signal time including Green and Flashing Green times. The proper pedestrian signal timing was calculated by analyzing pedestrian flows using actual data. In conclusion, given land use types, number of pedestrians, and crosswalk length and width; the appropriate pedestrian signal timings can be calculated using the proposed equation applying the proposed pedestrian starting time, the time interval between the pedestrian rows, and pedestrian crosswalking speed.

## 1. INTRODUCTION

A solution is seriously required to reduce pedestrian accident which accounts for more than 45 percent of total traffic accidents. Improper pedestrian signal timing has caused many problems at intersections of urban areas in Korea because the signal time is set for mainly vehicle operations. In 1993, pedestrian accidents occurring on crosswalks accounted for 4.6% of all trffic accidents (11,964 out of 260,921 accidents) in Korea resulting in 528 deaths and 13,528 injuries. Cross-walking speed of 1.2m/sec has been used as a fixed value for estimating pedestrian signal timing without considering Korean pedestrian characteristics.

The study found that drivers and pedesrians are misunderstanding the exact meaning of pedestrian signals because of a lack of documentation guiding the definition of the pedestrian signals. The main purpose of the research is to estimate the pedestrian signal time including Green and Flashing Green times based on the theoritical concept. The proper pedestrian signal timing will reduce traffic accidents at intersections.

Minimum signal cycle length and minimum pedestrian signal timing are often determined by the pedestrian crossing time. If the pedestrian crossing time set to less than the required time, the level of danger will be increased. On the other hand, if the pedestrian crossing time set to longer than the required time, the vehicle delays will be increased.

## 2. LITERATURE REVIEW

The Korean Manual on Traffic Safety Devices, a guide to installation and operation of traffic signal system, recommends the following equation to estimate the minimum pedestrian crossing time based on the crosswalking speed, the length and width of crosswalk, and the number of pedestrians.

$$PT = L/1.2 + 1.7(N/(W-1)) \quad (1)$$

where, PT = Minimum pedestrian crossing time, second
L = Length of crosswalk, meter

N = Number of pedestrain per one cycle
W = Width of crosswalk, meter

The equation uses a crosswalking speed of 1.2m/sec as a fixed value for estimating pedestrian signal timing without considering the pedestrian types. A parameter of 1.7 second is used as the pedestrian starting delay time assuming a constant value by rows. Furthermore, the following simple equation is used for calculating the minimum pedestrian crossing time without considering the number of pedestrian and crosswalk characteristics such as crosswalk width and land use types.

$$PT = L/V + T \qquad (2)$$

where, PT = Minimum pedestrian crossing time, second
L = Length of crosswalk, meter
V = Pedestrain crosswalking speed, m/sec
T = Maximum 5 seconds for starting allowance time, second

Mark Virkler had studied various evaluation techniqes on pedestrian behaviors at a signalized intersection (Virkler 1982). This study indicated that the minimum pedestrian timing could be estimated if the average crosswalking speed and the average pedestrian density were known. Traffic Engineering suggested the following equation which is assumed the constant gap (interval) time between the rows with five pedestrians in each row.

$$TGap = 3 + 2(N-1) + (L/3.5) \qquad (3)$$

where, TGap = Minimum pedestrian crossing time, second
3 = Assumed perception and reaction time, second
2 = Assumed time interval between rows (headway), sec
N = Number of rows assuming 5 pedestrians in each row
L = Length of crosswalk, feet

As mentioned earlier, the average crosswalking speed of 1.2m/sec has been used as a fixed value for estimating pedestrian signal timing based on the U.S. MUTCD. In the U.S., research on pedestrian characteristics found that the speed of 1.2m/sec (4 ft/sec) is not proper to use as the pedestrian crosswalking speed because the typical walking speed of 1.2m/sec as cited in the MUTCD is assumed to represent the "normal" pedestrian. However, there are various categories within the general population that walk at a slower rate. The research verify that over 60% of all pedestrians move slower than 4 ft/sec and 15% walk at or below 3.5 ft/sec (Kell, J.H. *et al* 1991).

The pedestrian crosswalking speeds were investigated at signalized intersections in Korea. On the basis of the male walking speed of 1.2m/sec and the female of 1.05m/sec, 56.0% (6,180 persons) of all pedestrians walk at slower than the basis (Han 1982). Korean Consumer Protection Agency found that 56.3% (171 persons) of surveyed pedestrians walk slower than the crosswalking speed of 1.2m/sec.

In Japan, the speeds of 1.0m/sec and 1.5m/sec apply to the Green time and the Flashing Green time, respectively. In Sweden, the speed range between 0.9 and 1.1m/sec is used in related to the environmental situtation. The speed of 1.2m/sec using in Korea is 9.5 to 33.3% faster than the other countries. Therefore, the different pedestrian crosswalking speeds should be carefully considered when deliberating crosswalk specifies for any given intersection. The pedestrian cross-walking speed at a signalized intersection should be estimated different from the typical walking speed of 1.2m/sec.

## 3. DATA

The city of Seoul was selected as a study area. An extensive data is needed to analyze the pedestrian signal timings because the pedestrian characteristics vary in trip purpose, population density, environmental situation, sex and age. However, data was manually collected at 20 intersections where there were high pedestrian accidents and signalized intersections with pedestrian signals and crosswalks. The 20 intersections were classified by four commercial areas, four business areas, ten mixed areas, and two elementary school areas. It was defined the mixed areas as residential areas combined with high rised apartments and areas near subway stations

The data was collected regards to the number of vehicle trips and lanes, vehicle and pedestrian signal times, crosswalk placement, crosswalk length and width, pedestrian crosswalking speed, the number of pedestrians by sex and age group, and the number of crosswalk violators by the type. The data was obtained during 150 cycles of a day per each crosswalk. The study limited the data collection times to good weather, weekday, and summer.

## 4. RESEARCH METHODOLOGY

The purpose of this study is to estimate the parameters of the following equation (4) based on the theoritical equation of the pedestrian signal timing including Green and Flashing Green times.

$$PT = (PRT + SDT + CLT) = t + H*(R-1) + (L/Vp) \tag{4}$$

where, PT = Minimum pedestrian crossing time, starting from the first pedestrian until complete crossing of the last ped, second
PRT = Perception reaction time, second
SDT = Starting delay time and interval time by rows, sec
CLT = Clearance time. second
t = Perception reaction time, second
H = Starting delay time by each row, second
R = Number of rows
L = Length of crosswalk, meter
Vp = Pedestrian crosswalking speed, m/sec

The minimum Green indication should give time to start crossing safely for all pedestrians who were waiting to cross. The minimum Flashing Green indication means that pedestrian shall not start to cross the roadway in the direction of the indication, but the indication should give time to proceed to a sidewalk or to a safety island for any pedestrian who has partly completed his crossing during the steady Green indication. Therefore, the equation (4) could be separated by the following:

- o $t + H*(R-1)$ = Minimum pedestrian Green time, second
- o $(L/Vp)$ = Minimum pedestrian Flashing Green time, second

The minimum pedestrian Flashing Green time should be estimated by the length of a crosswalk (L) and the pedestrian crosswalking speed (Vp) varied by intersection characteristics. The pedestrian crosswalking speed is calculated by the length of a crosswalk and crosswalking time, and the crosswalking time is affected by the number of pedestrian and the width of a crosswalk. Therefore, the pedestrian speed would depend on the pedestrian density. Also, the speed might be closely related to the pedestrian and intersection characteristics; such as, land use types, time of day, weather, and pedestrian sex and age. The level-of-service concept was applied to establish the standard that fits to various and complicated situations. The following procedures were used to estimate the minimum pedestrian Flashing Green time varied by land use types and level-of-service.

1. Calculate the average speeds by each cycle from the collected data
2. Obtain the 15th-percentile speed with consideration of safety.
3. Determine the number of pedestrian at each crosswalk by using the 85th-percentile number of pedestrian with consideration of safety, not the average number of pedestrian.
4. Calculate the pedestrian density using the following equation:

   $$DEN = Bn/(W*L) \quad (5)$$

   where, DEN = Pedestrian density (ped/$m^2$)
   Bn = Number of both direction pedestrians
   W = Width of crosswalk, meter
   L = Length of crosswalk, meter

5. Infer a relationship between the 15th-percentile speed and the density; then, establish the level-of-service by the density and land use type. Calculate the crosswalking speeds of the design pedestrian for the minimum pedestrian Flashing Green time based on the determined level-of-service and land use type.

The pedestrian starting time (perception/reaction time) and headway time from front to back of the pedestrian group should be estimated for determining minimum pedestrian Green time. In order to obtain the time interval between rows, the number of rows should be estimated by the following equation assuming pedestrian side space of one meter:

$$R = N/(W+1) \quad (6)$$

where, R = Number of rows
N = Total number of pedestrian by each cycle
W = Width of crosswalk, meter

The study was statististically analyzed not only the pedestrian speeds and density, but also the pedestrian starting time (perception/reaction time) and the headway time from front to back of group. The pedestrian starting time (perception/reaction time) of three to seven seconds is generally used in other countries. The 85th-percentile of the actual starting delay time is used in this study. Also, the time interval is calculated by the following procedures:

1. Use only the number of rows more than one row.
2. Calculate the time interval between rows using the following:

   $$H = (TS - TO)/(R - 1) \quad (7)$$

   where, H = Time interval between rows, second
   TS = Time the last ped among the waiting ped stepped on the crosswalk
   TO = Set zero when ped Green indication light on
   R = Number of rows calculated from equation (6)

3. Categorize the calculated time interval (H from equation (7)) by the number of rows (R); then, obtain the 85th-percentile time interval.

## 5. DATA ANALYSIS

The research is not to analyze data collected for a certain area of the intersections, but is to provide general guidelines for pedestrian signals at any given intersection. The 20 Seoul-area intersections were selected for data collection. The data colloction of this study required the total 375 man-days for two months, and the total 5,189 cycle times investigating 215,391 pedestrians.

In many intersections, it was found that the space was not enough to accomodate the waiting pedestrians, and that the pedestrian signal timing was shorter than the time required to complete crossing the crosswalk safely. The commercial areas indicated the largest number of pedestrians, followed by the business, mixed, and elementary school areas, in that order. The mixed areas showed the highest traffic violators followed by the commercial, business, and elementary school areas in that order.

### 5.1 Crosswalk Speed Comparisons by Land Use Types

The pedestrian speeds generated at each intersection were classified into the four groups of land use types. The frequency distributions of the pedestrian speed were statistically estimated by land use types. Figure 1 shows the pedestrian speed distribution by land use types. The curves indicate the normal distribution with the exception of the school area. Unlike the distribution of the school area, there are two convex curves because the left side of the curve is mainly caused by pupils, and the right side is caused by rare frequencies of adults.

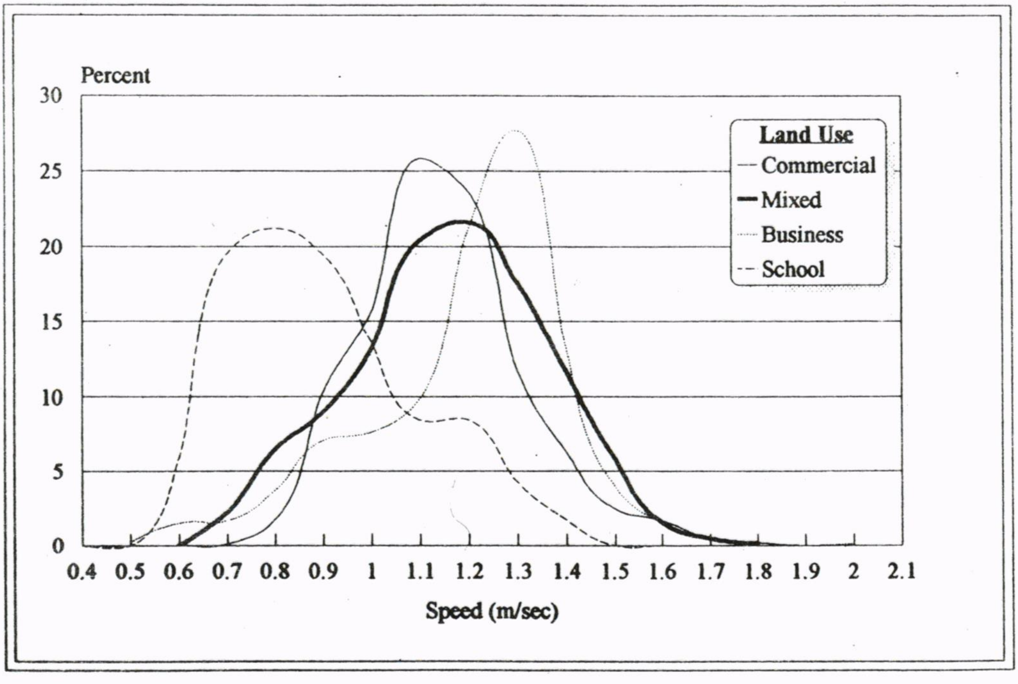



**Figure 1. Pedestrian Speed Distribution by Land Use Types**

Table 1 shows the statistical measures used to compare the pedestrian speed by land use types. Table 1 indicated that the pedestrians in the business area walk faster than other area pedestrians, and pupils walks slower than others. The pedestrians in the mixed area shows high variations of the speeds because of various pedestrian types. An average walking speed of 1.11 m/s was estiamted by analyzing the collected data which was slower than the 1.2 m/s.

Table 1. Statistical Measures of Crosswalk Speed by Land Use Types

(Unit: m/sec)

| Area Type | Number of Data | Average Speed | Standard Deviation | 15th-% Speed | 85th-% Speed |
|---|---|---|---|---|---|
| Commercial | 1646 | 1.10 | 0.17 | 0.92 | 1.37 |
| Mixed | 2229 | 1.11 | 0.20 | 0.83 | 1.43 |
| Business | 1147 | 1.17 | 0.17 | 0.91 | 1.49 |
| School | 121 | 0.86 | 0.19 | 0.65 | 1.19 |
| Total | 5143 | 1.11 | 0.18 | 0.84 | 1.37 |

## 5.2 Pedestrian Distribution by Time of Day

In order to compare the pedestrian distributions by time of day, four intersections representing each land use type were selected based on similar characteristics of cycle length, number of data collected, and number of pedestrians. Figure 2 shows the pedestrian distribution by time of day and land use type. The number of pedestrians in commercial areas was evenly distributed, except for offpeak nighttime. The largest number of pedestrians in business areas occurred during the afternoon, while the lowest number of pedestrians occurred during morning and nighttime hours. In school areas, the number of pupils increased shortly before school began. However, two groups of pupils were shown at afternoon because the dismissing times are different by each grade.

## 5.3 Density Distribution by Land Use Types

The pedestrian density was calculated using the number of both direction pedestrians for each cycle length divided by crosswalk area multiplying 100 (see equation (5)). Table 2 shows the estimated results of the average pedestrian density by land use types.

Table 2. Statistical Measures of Pedestrian Density by Land Use Types

(Unit: $(Ped/m^2)x100$)

| Area Type | Number of Data | Average Density | Standard Deviation | 15th-% Density | 85th-% Density |
|---|---|---|---|---|---|
| Commercial | 1646 | 23.17 | 13.29 | 9.14 | 34.17 |
| Mixed | 2229 | 22.46 | 19.17 | 6.00 | 44.13 |
| Business | 1147 | 15.03 | 10.10 | 5.94 | 24.17 |
| School | 121 | 27.31 | 17.59 | 8.17 | 44.93 |
| Total | 5143 | 21.14 | 15.23 | 7.31 | 36.85 |

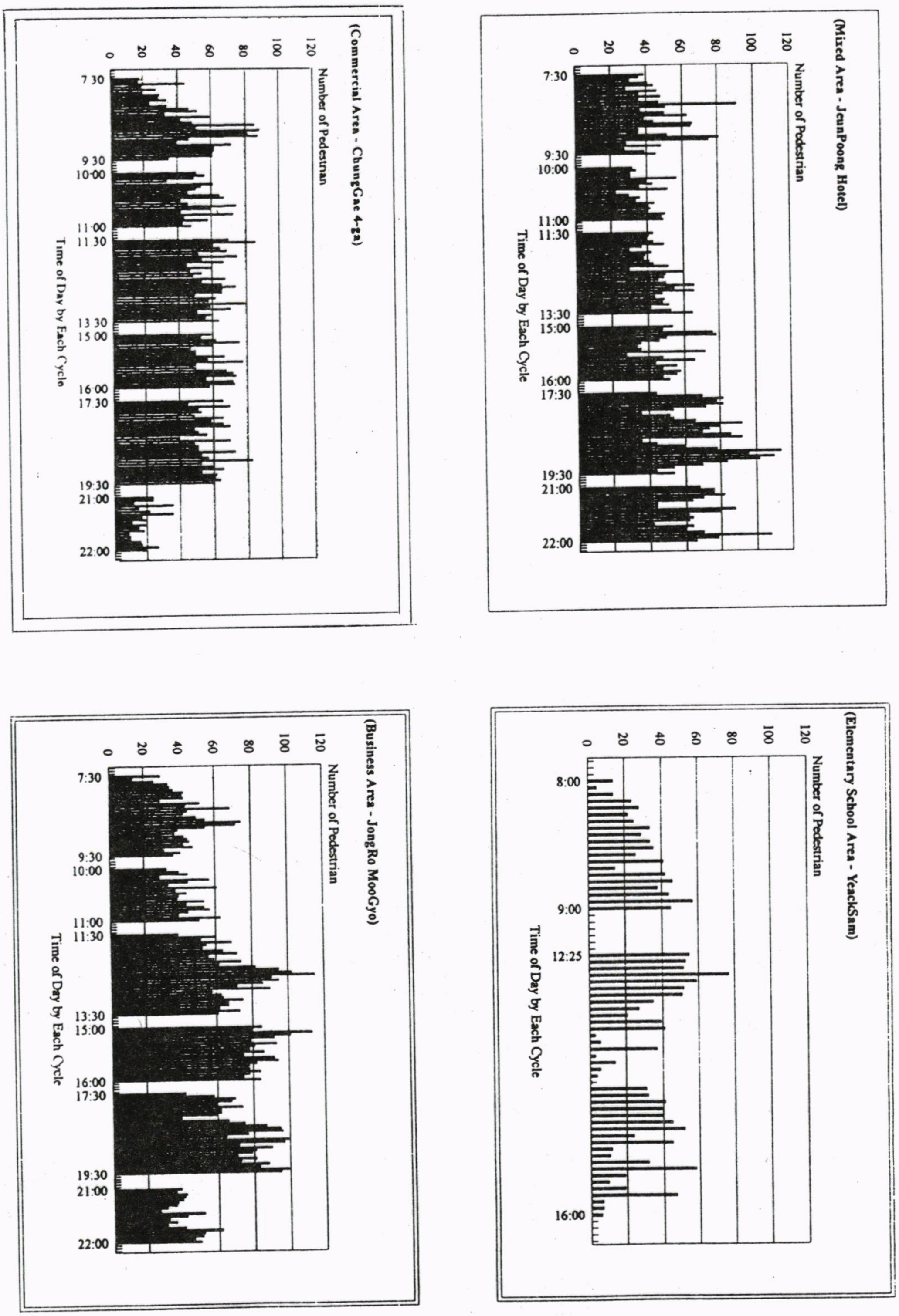



Figure 2. Pedestrian Distributions by Time of Day and Land Use Type

Table 2 indicated that school areas had the highest pedestrian density because the crosswalk area is small with the large number of pupils crossing to attend school. However, the large number of pedestrians collected in business area showed the small pedestrian density because the crosswalk area is large and usually located along the major arterial street. Also, business areas indicated the distribution of the pedestrian density, evenly. Figure 3 shows the distribution of the pedestrian density by land use types that indicated the log-normal shape rather than the normal distribution. The shape of curve in mixed area indicated that the pedestrian density is widely distributed because of various land use activities. The right side of school area is abnormally distributed due to the different dismissing times by each grade.

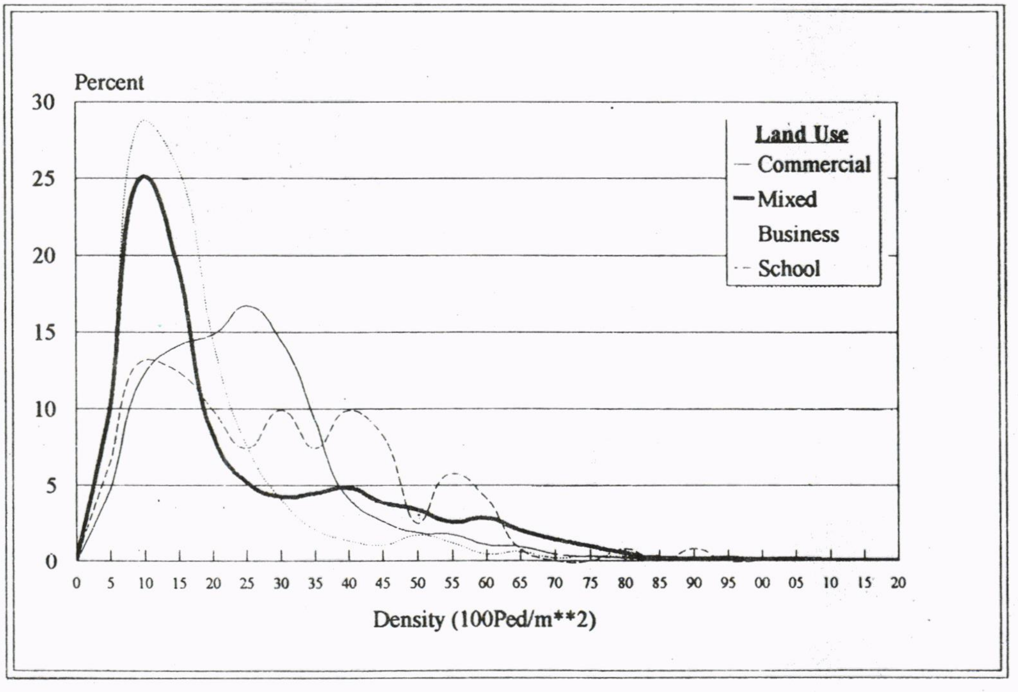


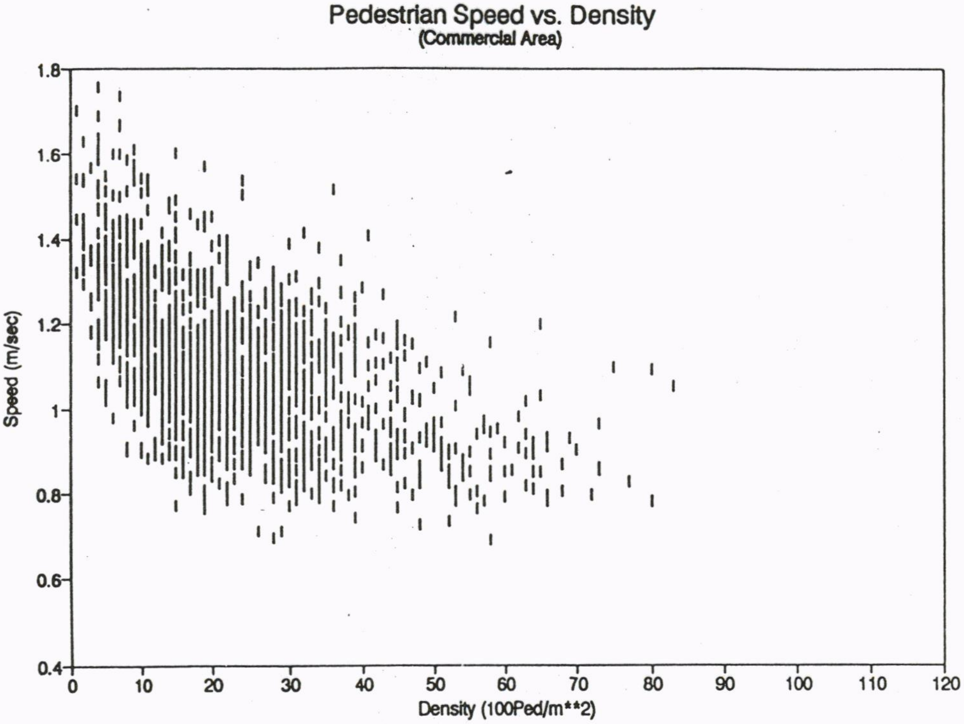

Figure 3. Distribution of Pedestrian Density by Land Use Types

## 6. DATA EVALUATION

### 6.1 Pedestrian Speed-Density Relationship

As density increase, speed tends to decrease linearly. Figures 4 and 5 illustrates the relationships between the pedestrian crosswalking speed and the pedestrian density using scatter diagrams. The research hypothesis of the T-Test is as follows:

$H_0$ = No relationship between speed and density
$H_1$ = Existence of relationship between speed and density
Accept Region: Reject $H_0$ if the calculated value of T is larger than the tabulated critical value for $\alpha = 0.05$ and $df$ = n-1



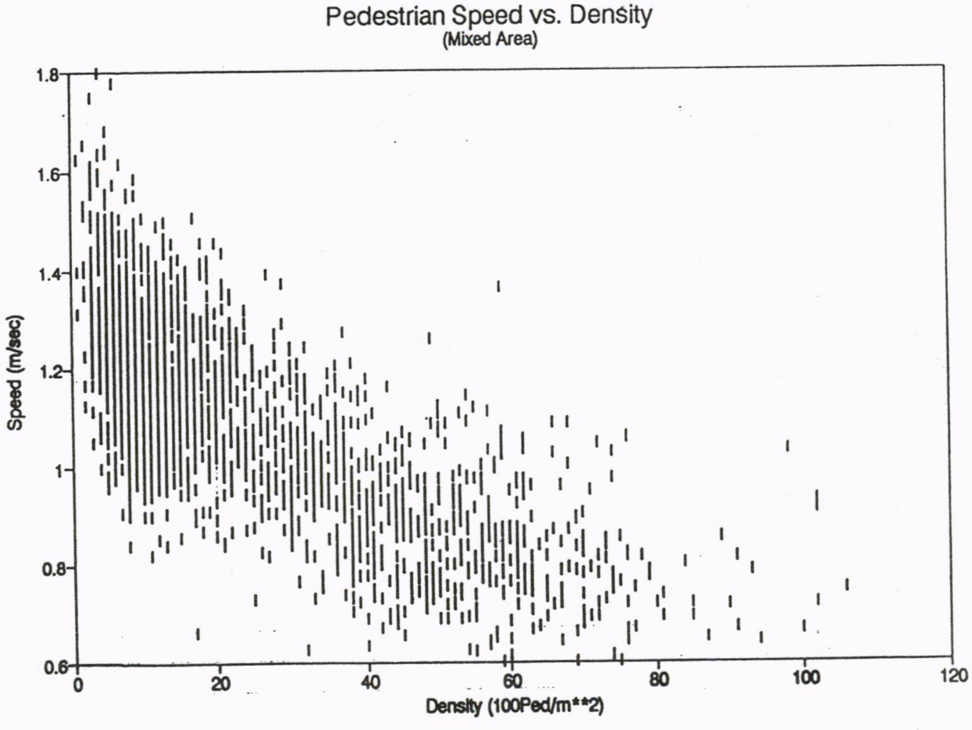
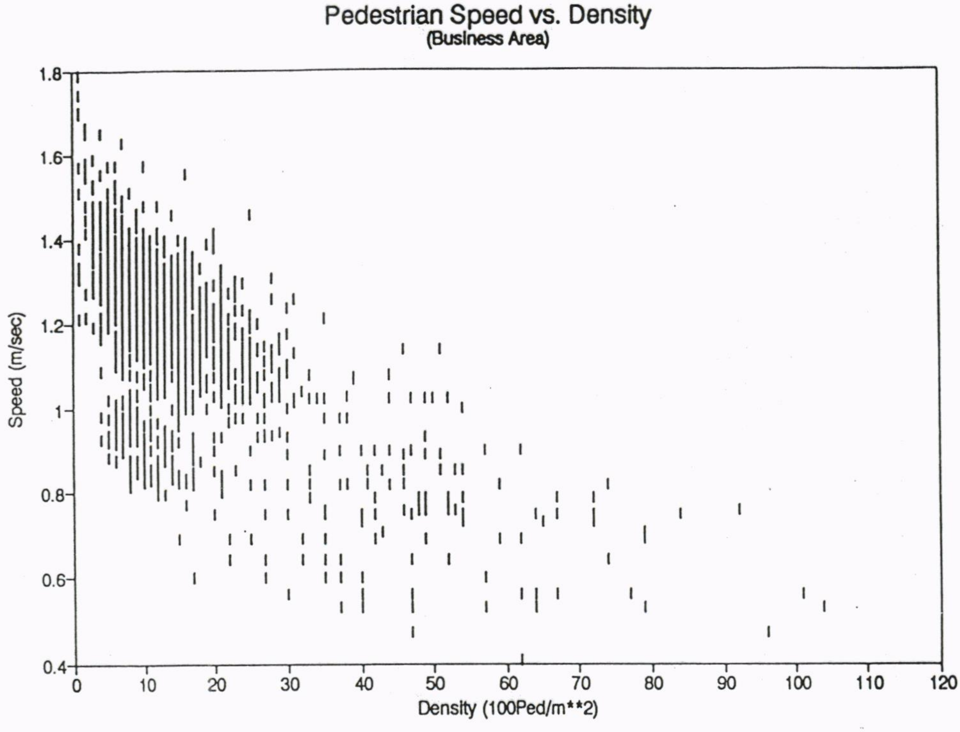




Figure 4. Relationships Between Pedestrian Speed and Density (Commercial and Mixed Areas)



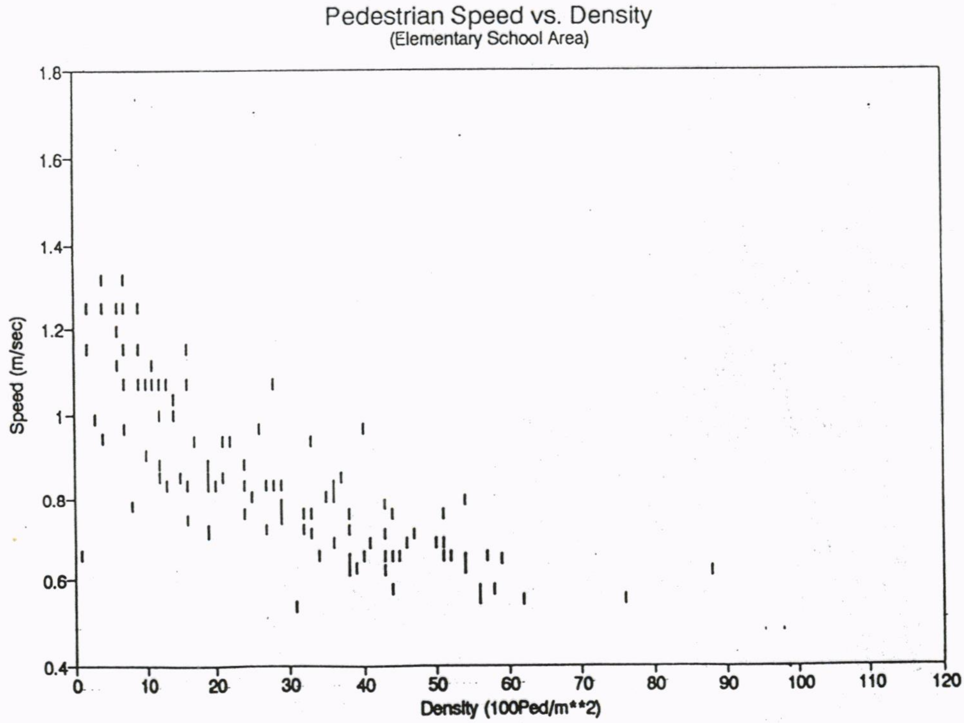




Figure 5. Relationships Between Pedestrian Speed and Density (Business and Elementary School Areas)

To test the research hypothesis, the pedestrian density was considered the indepedant variable, and the pedestrian crosswalking speed was the dependant varlable. It was concluded that there is a significant relationship between the pedestrian crosswalking speed and the pedestrian density. The linear regression model was selected as the best fit model by testing several regression models.

## 6.2 Pedestrian Level-Of-Service by Density

It was found that there is a siginificant relationship between the pedestrian crosswalking speed and the pedestrian density, and that speed tends to decrease linearly as density increase. The level-of-service was determined by the following procedure:

1. Obtain the calculated linear regression models by land use types:
   - Commercial: Speed = 1.25-(0.0066xDensity), ($R^2$=0.27, F=611)
   - Mixed: Speed = 1.28-(0.0077xDensity), ($R^2$=0.53, F=2528)
   - Business: Speed = 1.29-(0.0082xDensity), ($R^2$=0.24, F=363)
   - School: Speed = 1.09-(0.0086xDensity), ($R^2$=0.62, F=192)
2. Plot the lines using the calculated regression models by land use types (See Figure 6).
3. Analyze the level-of-service by land use types.
4. Determine the level-of-service related to the speed and density (See Table 3).

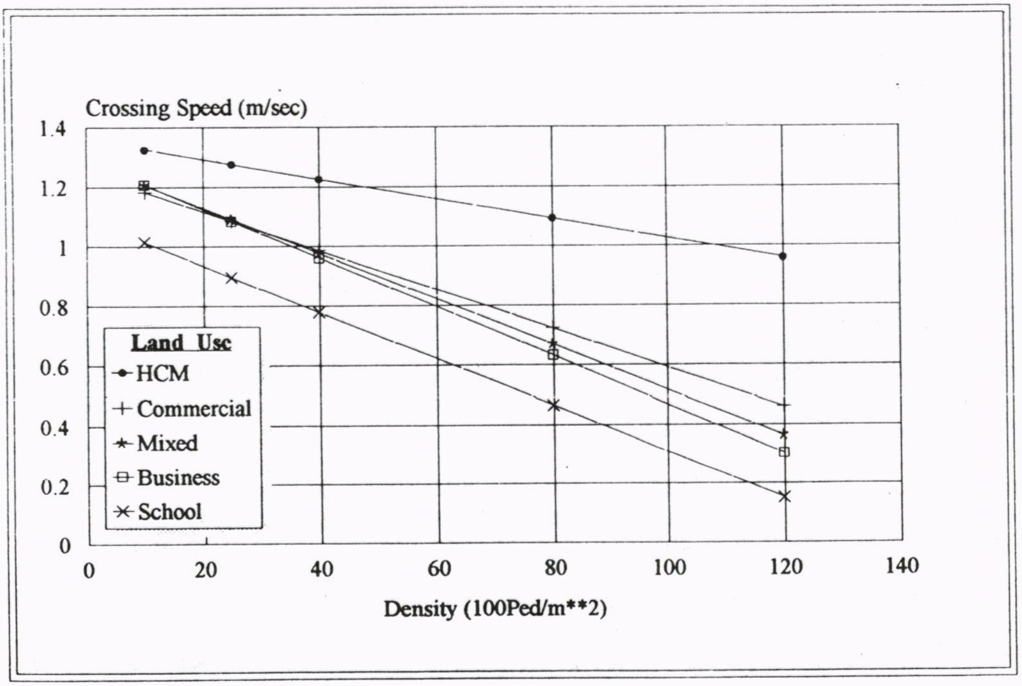



Figure 6. Calculated Models for Speed-Density Relationships

Figure 6 shows the speed-density relationships by land use types. All three areas except the shool area illustrated the similar speed-density distributions, also incidated that the calculated speeds were slower than the HCM speed.

Table 3. Pedestrian Level-of-Service by Speed and Density

| Level of Service | Density[1] ($ped/m^2$) × 100 | HCM Ave. Speed (m/sec) | Average Speed by Area Types (m/sec)[2] | | | |
|---|---|---|---|---|---|---|
| | | | Commercial Area | Mixed Area | Business Area | School Area |
| A | <10 | 1.326 | 1.182 | 1.206 | 1.207 | 1.013 |
| B | <20 | 1.276 | 1.084 | 1.091 | 1.084 | 0.896 |
| C | <40 | 1.226 | 0.985 | 0.976 | 0.961 | 0.778 |
| D | <80 | 1.093 | 0.723* | 0.670* | 0.632* | 0.465* |
| E | <120 | 0.960 | 0.461* | 0.363* | 0.303* | 0.152* |
| F | >120 | <0.960 | <0.363* | <0.363* | <0.303* | <0.152* |

Note, 1) Source from HCM TRR Special Report 209
2) * indicated that the speeds under level-of-service C should be used by replacing with the level-of-service C speed because the speeds were unrealistically calculated from the regression models.

An average walking speed of 1.11 m/s was estimated by analyzing the collected data which was slower than the HCM speed of 1.2 m/s. Furthermore, Table 3 shows that design speed for the Flashing Green time should be slow speed (0.96-1.21 m/s) for considerations of pedestrian safety based on the land use types, not the average speed. The 0.78-1.01 m/s of pedestrian speed was estimated at the elementary school areas that indicated 0.2 m/s slower than the other area. This fact was indicated that the child's walking speed is much slower than the adult's speed. Therefore, the pedestrian signal time should be longer in the elementary school areas for the children's safety.

### 6.3 Pedestrian Signal Timing Calculation

The minimum pedestrian Green indication should give time to start crossing safely for all pedestrians who were waiting to cross. The minimum pedestrian Flashing Green indication means that no pedestrian shall start to cross the roadway in the direction of the signal indication, but the indication should give time to proceed to a sidewalk, or to a safety island for any pedestrian who has partly completed his crossing during the steady Green indication.

In order to estimate the minimum pedestrian Flashing Green time, the length of a crosswalk (L) is simply divided by the estimated pedestrian crosswalking speed (Vp) varied by intersection characteristics of land use types and level-of-service.

Minimum pedestrian Flashing Green time = (L/Vp)

The pedestrian starting time (perception/reaction time) and headway time from front to back of a group of pedestrians should be estimated for determining minimum pedestrian Green time. The pedestrians waiting for the Green signal indication showed the fast perception/reaction time because the cycle length is usually longer than the 120 seconds. Also, the study results showed that the pedestrians perceived and reacted more quickly as the pedestrian rows increases.

It was noticed that the time interval between the pedestrian rows declined as the pedestrian rows increased.

In order to obtain the pedestrian starting time and the time interval between rows, the number of rows was estimated by the number of pedestrian by each cycle and the width of crosswalk assuming pedestrian side space of one meter. Figure 7 shows the frequency distribution of the pedestrian starting perception/reaction time. The pedestrian starting time of three to seven seconds is generally used in other countries. The 85th-percentile of the actual starting delay time is used in this study. It was found that the starting time indicated constant values after the number of rows of four. The time of 2.52-4.39 seconds were estimated for the pedestrian starting time. Also, the time of 1.25-1.86 seconds were estimated for the time interval between the pedestrian rows based on the mean time and linear regression. Table 4 shows the minimum Green time according to the number of rows.

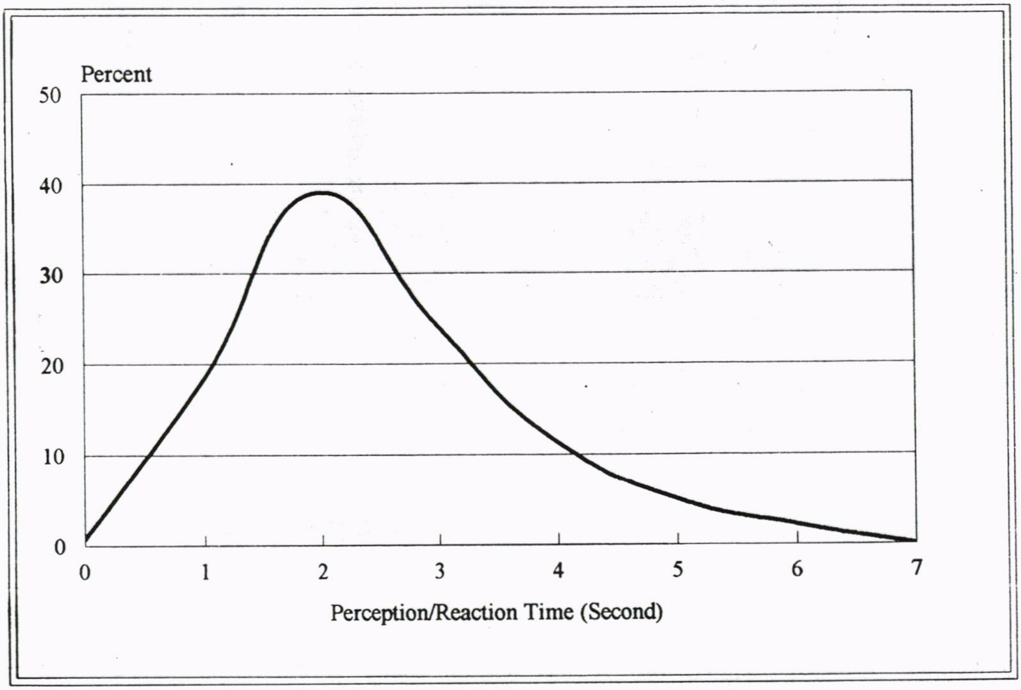



Figure 7. Frequency Distribution of Pedestrian Starting Perception/Reaction Time

Table 4. Minimum Green Time By Number of Rows

(Unit: Seconds)

| The Number of Rows, R | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Starting Time, t | 4.39 | 3.77 | 3.14 | 2.52 | 2.52 | 2.52 |
| Time Interval, H | 0.00 | 1.86 | 1.65 | 1.45 | 1.25 | 1.18 |
| Resulted Minimum Green Time | 4.39 | 5.63 | 6.45 | 6.88 | 7.52 | 8.43 |

The minimum Green time is the sum of the pedestrian starting time and the time interval between rows, and increases as the number of rows increases (See Figure 8). Therefore, if the number of pedestrians (N) and the width of crosswalk (W) are known, the pedestrian Green signal time are calculated using the following proposed equation applying the proposed pedestrian starting time (t) and the time interval between the pedestrian rows (H).

$$\text{Minimum pedestrian Green time} = t + H^{*}(R-1)$$
$$\text{where, } R = N/(W+1)$$

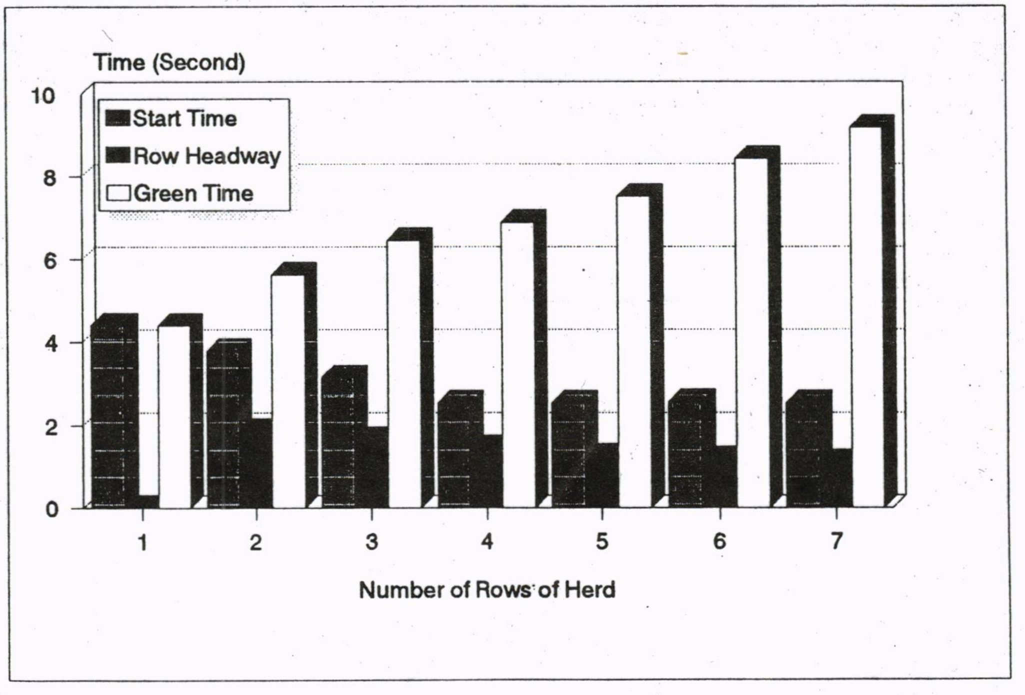



Figure 8. Minimum Green Time by the Number of Pedestrian Rows

## 7. CONCLUSION

Improper pedestrian signal timing has caused many problems at intersections in urban areas of Korea because the intersection signal timing is set primarily for vehicle operations. A solution was required to reduce the pedestrian accidents which account for more than 45 percent of total traffic accidents. The purpose of this research is to find proper pedestrian signal timing to reduce the pedestrian accidents at intersections in Korea.

The research is not for analyzing a certain area of an intersection by the data collected, but is to provide a general guideline for pedestrian signals at any intersection. The 20 intersections of Seoul area were selected for data collection. The proper pedestrian signal timing was calculated by analyzing pedestrian flows using the actual data. Therefore, the main purpose of the research is to estimate the pedestrian signal timing including Green and Flashing Green times based on the theoritical concept.

The crosswalking speed of 1.2 m/sec is using as a fixed value for estimating pedestrian signal times without considering Korean pedestrian characteristics. Also, the very simple method is used for calcualting the pedestrian signal timing without considering the number of pedestrian and crosswalk characteristics such as crosswalk width and land use types.

The study proved the fundamental linear relationship between pedestrian walking speed and density, and the fact that as density increases, pedestrian speed declines. The distribution relationship between pedestrian speed and density was analyzed based on land use types. The level-of-service (LOS) was determined by density and land use types. An average walking speed of 1.11 m/sec was estimated by analyzing the collected data which was slower than the 1.2 m/sec. Furthermore, the study proposed that design speed for the Flashing Green time should be slow speed (0.96-1.21 m/s) for considerations of pedestrian safety based on the land use types, not the average speed.

The 0.78-1.01 m/s of pedestrian speed was estimated at the elementary school areas that indicated 0.2 m/s slower than the other area. This fact was indicated that the child's walking speed is much slower than the adult's speed. Therefore, the pedestrian signal timing should be longer at the elementary school areas for the children's safety.

The pedestrian starting time (perception/reaction time) and headway time from front to back of a pedestrian group was estimated for determining minimum pedestrian Green time. The time of 2.52-4.29 seconds were estimated for the pedestrian starting time. The time of 1.25-1.86 seconds were estimated for the time interval between the pedestrian rows based on the mean time and linear regression. The study showed that the time interval between the pedestrian rows declined as the pedestrian rows increased.

In conclusion, if land use types (commercial, business, mixed, and elementary school), number of both-directional pedestrians for a cycle (85th percentile), and crosswalk length and width are given; the pedestrian signal timings including Green and Flashing Green times are calculated using the proposed equation applying the proposed pedestrian starting time, the time interval between the pedestrian rows, and pedestrian crosswalking speed.

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