EVALUATION OF PEDESTRIAN FACILITIES AT SIGNALIZED INTERSECTIONS IN METRO MANILA

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Abstract: Nineteen crosswalks in Metro Manila were surveyed and several variables assessed. Pedestrian flow characteristics and crosswalk variables were measured during selected times of the day. A model for pedestrian non-compliance was developed using several explanatory crosswalk variables. The model showed that non-compliance is greatly influenced by pedestrian volume, crosswalk width, and the availability of pedestrian traffic signals. To determine the effect of pedestrian non-compliance on pedestrian delay, a second model was developed using average delay as the response variable. Using estimates from the standard pedestrian delay equation and non-compliance data gathered in the field as explanatory variables, the model showed a high r-square value (r^2=0.932). Other statistical tests prove the model's high significance and low probability of error in accepting the result as valid. The resulting equations should be validated in other areas and may prove useful when evaluating the quality of pedestrian flow at signalized intersections.

Key Words: pedestrian facilities, signalized intersections, non-compliance, pedestrian delay

1. INTRODUCTION

According to a survey conducted by the Philippine Daily Inquirer in June 2000, the lack of pedestrian facilities is the top shortcoming of living and working in metropolitan Manila. This only means that pedestrian welfare is a bigger concern than pollution or traffic as far as the populace is concerned. However, limited projects have been undertaken to remedy this problem. As a result, there are no local standards for the design and construction of roadways that would be effective as passageways not only for vehicles but for pedestrians as well.

The pedestrian population copes with this inadequacy by not complying with traffic signals and by using facilities other than those specifically designed for them. Among these facilities are crosswalks at signalized intersections where pedestrians cannot be fully accommodated and where pedestrian non-compliance indicates their inefficiency.

To deal with this problem, an accurate prediction of pedestrian delay is necessary to evaluate the quality of pedestrian flow at crosswalks, especially in areas wherein density is high. Models of pedestrian delay are based on the assumption that pedestrians proceed only when the green signal is given. In the Philippine setting, however, this is not the case as pedestrians will ignore the indicated pedestrian signal to minimize their own delay. Delay prediction, in this case, would entail analyzing and eventually incorporating the effects of pedestrian non-compliance. At the same time, it is also important to examine what physical factors (i.e.

crosswalk characteristics) contribute to a pedestrian's likelihood in violating signal indications.

In essence, this study focuses on determining relationships between crosswalk variables and pedestrian non-compliance at signalized intersections. It also sheds more light on the implications of non-compliance on pedestrian traffic flow, specifically delay, and allows the formulation of more appropriate delay equations for pedestrians in the local setting

The results of this study should also prove useful in assessing the performance and adequacy of existing signalized crosswalks, as well as in developing appropriate crosswalk design and level-of-service standards for future applications.

2. OBJECTIVES OF THE STUDY

The general objectives of this study are to create models to describe the relationship between crosswalk variables and pedestrian non-compliance, and determine the effect of non-compliance on pedestrian signal delay.

3. RELATED LITERATURE

Several formulas are used to compute for pedestrian delay. Braun and Roddin (1978) developed the following equation that assumes continuous arrival of pedestrians, constant cycle length, no pedestrian actuation, and complete signal compliance:

$$d = \frac{(C - G)^2}{2C} \qquad \text{(Eq 1)}$$

where: d = average stopped delay per pedestrian (sec.)
C = cycle length of the intersection
G = duration of pedestrian green signal

Braun and Roddin modified this to account for pedestrian non-compliance, as shown below:

$$d = \frac{F(C - G)^2}{2C} \qquad \text{(Eq.2)}$$

where F = fraction of pedestrians who obey signal

However, in this formulation, non-complying pedestrians are assumed to receive no delay. This, of course, is not true in the field because non-complying pedestrians are also subject to delay as those who comply with signals, but to a lesser degree.

For this reason, Virkler (1998) postulated a potential modification of this equation by assuming that some portion of the clearance interval (flashing red) will be used for entering the crosswalk. In his study, it appeared that about 69% of the clearance period were used as if it were effectively green, as shown below:

$$d = \frac{[C - (G + 0.69A)]^2}{2C} \qquad \text{(Eq.3)}$$

where A = duration of clearance or flashing red signal

While Eq.3 may be useful for areas where non-compliance occurs during the clearance period, it is not be applicable in intersections wherein violators extend the length of effective green time to include a portion of the red signal.

In the Philippines, it is often observed that pedestrians usually start crossing before the green signal is given, and continue to do so even after the red indication. This phenomenon has not been taken into account in any of the equations given above and may therefore cause discrepancies in delay estimation.

4. STUDY FLOW

Figure 1 shows the structure of the study. The study starts with data collection through a delay and non-compliance survey, and an inventory of pedestrian facilities. The results of both surveys are then integrated through modeling and then analyzed for possible relationships. The study ends with the conclusions and recommendations of the whole study.

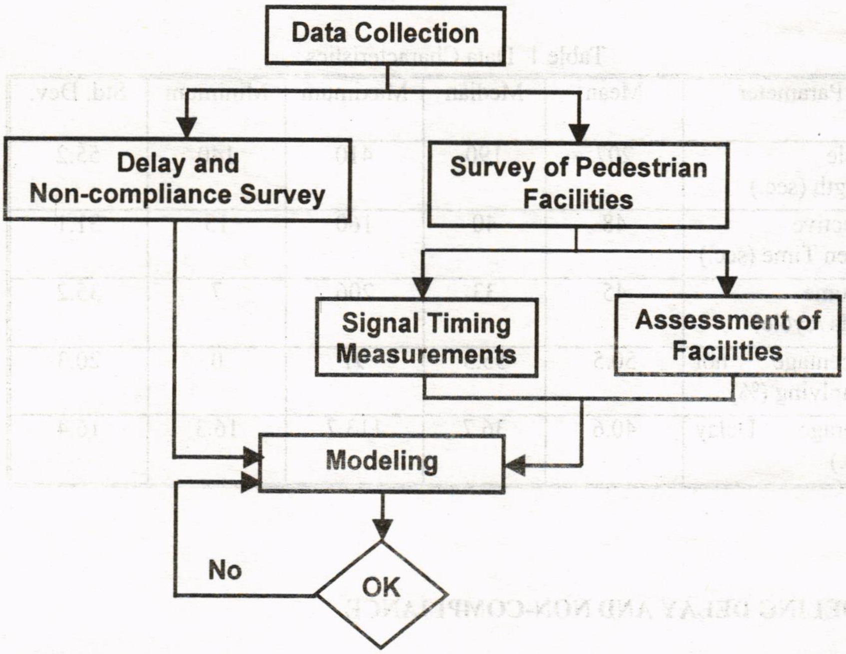

Figure 1. Study Flow Diagram

Due to this study's time limitations and financial constraints, 6 pre-selected intersections in Metro Manila (specifically the cities of Pasay, Makati, Manila and Quezon City) were surveyed. The study sites were selected to represent portions of important pedestrian routes carrying significant volumes at both peak and off-peak hours of the day. The intersections mentioned above yielded data from 19 crosswalks. All crosswalks were videotaped for a minimum of three cycles and were observed twice during the day leading to a total of 110 cycles for all crosswalks. The time periods for data collection were between 7:00 to 9:00 AM and 1:00 to 3:00 PM on weekdays. The data collected consisted of:

(1) the volume of pedestrians using the crosswalk,
(2) the number of pedestrians who enter the crosswalk when there is a conflicting vehicular movement (referred to as "non-complying"), and
(3) the stopped time delay of pedestrians using each crosswalk direction.

Pedestrians were selected randomly from each cycle and their delay was measured using a standard stopped delay measurement technique often used in vehicle studies (HCM, 1985). Each person stopped represented *t* seconds of delay, and the average delay was computed by dividing the total person-seconds of delay for one cycle with the number of observations.

As shown in Table 1, the intersections had cycle lengths that were longer than the HCM standard of 60 to 180 seconds. Observing the crosswalks twice during the day yielded data for pedestrian volume ranging from 7 peds/cycle during off-peak to 206 peds/cycle at peak hours. Varying degrees of non-compliance ranged from 0 to 91%.

Table 1. Data Characteristics

Parameter	Mean	Median	Maximum	Minimum	Std. Dev.
Cycle Length (sec.)	207	190	410	140	55.2
Effective Green Time (sec.)	48	40	160	15	31.1
Volume (peds./cycle)	45	33	206	7	35.2
Percentage not complying (%)	50.5	55.3	91	0	20.3
Average Delay (sec.)	40.6	36.7	113.7	16.3	16.4

5. MODELING DELAY AND NON-COMPLIANCE

5.1 Model Structure

Figure 2 shows the model structure of the study. The first sub-model relates non-compliance with several crosswalk variables. The data obtained from the assessment of pedestrian signals, pavement markings, safety railings, pedestrian signs, and obstructions at crosswalks; as well as the raw data from observations of pedestrian violation (as a ratio of volume) served as inputs for the non-compliance model.

In the second sub-model, cycle length, pedestrian green time and non-compliance were used as explanatory variables for actual delay.

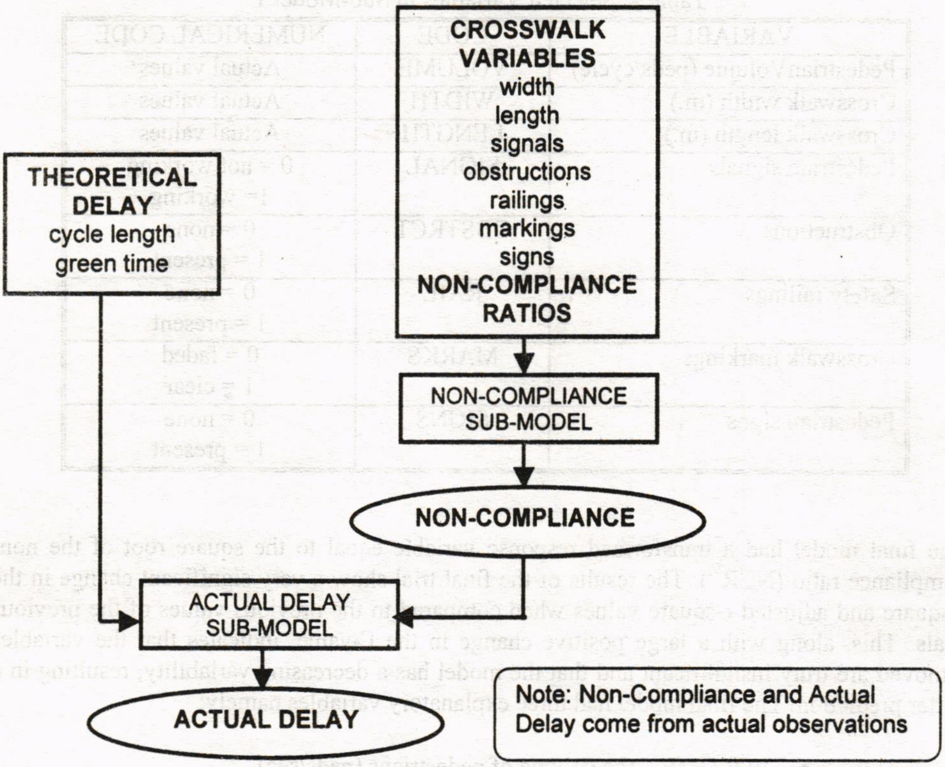

Figure 2. Structure of the Model

5.2 Sub-Model 1 Estimation

There were several variables assessed at each crosswalk in terms of condition or availability. These variables were pedestrian volume per cycle, pedestrian signals, signs, safety railings, and crosswalk markings. Factors affecting pedestrian flow such as crosswalk geometry and the presence of obstructions were also included in the assessment. The presence of refuge islands was excluded as a variable since some of the intersections surveyed did not have them. With the exception of pedestrian volume and crosswalk geometry, all were encoded as binary variables and followed the coding seen in Table 2.

Multiple regression was used as a means to examine how these variables affected the degree of pedestrian non-compliance occurring at each of the crosswalks. Non-compliance as a ratio of total number of pedestrians was designated as the response variable. Given that some of the independent variables are predisposed as correlated, a "kitchen-sink" type of regression, wherein no variables are excluded from the initial run of the model, was first analyzed. This resulting model indicated the lack of effect some variables have to non-compliance. Because of this, the dependent variable underwent several transformations, and by using a trial-and-error method, the regression was repeated and relatively insignificant explanatory variables were removed until a good fit was found.

Table 2. Selected Variables in Sub-Model 1

VARIABLE	CODE	NUMERICAL CODE
Pedestrian Volume (peds/cycle)	VOLUME	Actual values
Crosswalk width (m.)	WIDTH	Actual values
Crosswalk length (m.)	LENGTH	Actual values
Pedestrian signals	SIGNAL	0 = not working 1= working
Obstructions	OBSTRCT	0 = none 1 = present
Safety railings	RAIL	0 = none 1 = present
Crosswalk markings	MARKS	0 = faded 1 = clear
Pedestrian signs	SIGNS	0 = none 1 = present

The final model had a transformed response variable equal to the square root of the non-compliance ratio ($NCR^{½}$). The results of the final trial show a very significant change in the r-square and adjusted r-square values when compared to the previous values of the previous trials. This, along with a large positive change in the F-value, indicates that the variables removed are truly insignificant and that the model has a decreasing variability, resulting in a better prediction. The final model had three explanatory variables namely:

- VOLUME – the volume of pedestrians (peds/sec)
- WIDTH – the crosswalk width, measured in meters
- SIGNALS – availability of pedestrian signals (working, not working)

Correlation tests show very low correlation values between the three independent variables thus eliminating any chance of redundancy. The resulting equation from the non-compliance model is:

$$\mathbf{NCR^{1/2} = 0.911 - 0.339V - 0.042W - 0.433S} \quad \text{(Eq.4)}$$

where $NCR^{1/2}$ = the square root of the non-compliance ratio
V = the volume of pedestrians, expressed in peds/cycle
W = the width of the crosswalk, expressed in meters
S = factor for availability of pedestrian signal (0 = not working, 1 = working)

Table 3 gives the summary of the model's final run. The regression coefficients (or B coefficients) represent the independent contributions of each explanatory variable to the prediction of the response variable. It is shown that all explanatory variables have negative coefficients indicating a negative correlation with non-compliance.

The coefficient of the variable SIGNALS has the greatest absolute value and is thus expected to have the greatest effect on non-compliance. In other words, non-compliance is most sensitive to the availability of pedestrian signals. This means that pedestrians are more likely to violate traffic rules at signalized intersections when signals are not functioning or are damaged. The most common damages observed were barely visible lighting, broken or cracked lenses, and faulty placement of signals. The relationship between pedestrian signals and non-compliance is quite logical, in that any deficiency in pedestrian signal operation would result in the loss of guidance for pedestrians wanting use the crosswalk.

Table 3 also indicates that non-compliance has a significant negative correlation with the variable VOLUME. The less the volume of pedestrians the more likely it is that pedestrians will violate the given signal. This may be because in a large group waiting to cross, it is more difficult to move individually when the rest are not moving. On the other hand, if there are only a handful of pedestrians at the street corner or refuge, it is easier to cross regardless of vehicular conflict.

Table 3. Estimation Results of Sub-model 1: Dependent Variable: $NCR^{1/2}$

N = 110	BETA	STD. ERROR OF BETA	B	STD. ERROR OF B	T(106)	P-LEVEL
Intercept			0.911	0.158	5.780	0.000
VOLUME	-0.108	0.057	-0.339	0.180	-1.890	0.062
WIDTH	-0.066	0.057	-0.042	0.036	-1.158	0.249
SIGNALS	-0.793	0.057	-0.433	0.031	-13.988	0.000

Although the variable WIDTH was found to have a minimal influence on non-compliance, it is still significant relative to the other variables used in the regression analysis. The negative value of its coefficient signifies that the narrower the crosswalk, the greater the likelihood that pedestrian violations will occur. A narrow crosswalk width results in slower dispersion of pedestrians, such that those who are in a position to cross will most likely do so to avoid further delay.

Table 4. Regression Summary for Dependent Variable: $NCR^{1/2}$

R	0.813
r^2	0.661
Adjusted r^2	0.651
F(3,106)	68.872
p-level	<0.000
Std. Error of Estimate	0.157

With respect to the other models tested, the r-square value ($r^2 = 0.661$) denotes a relatively good fit implying that 66% of the original variability in data is accounted for (Table 4). The F-statistic for 3 and 106 degrees of freedom is found to be way above the critical value of +2.68 and the value of the p-level ($p<0.000$) means that there is a low probability of error in accepting that the observed relation between the variables is a reliable indicator of the relation between the respective variables in the population. Therefore, the observed result is valid and is representative of the population.

5.3 Sub-model 2 Estimation

Theoretical delay was estimated by applying the signal timing data to both Braun and Roddin's pedestrian delay equations for each of the 19 crosswalks. As stated earlier, the equations assume the continuous arrival of pedestrians, no pedestrian signal actuation, and that pedestrians who violate the signal receive no delay. These estimates were then tested for correlation with actual average delay (AAD) and the percentage difference in estimation was determined. Both equations showed high correlation values and similar estimation (Table 5).

Table 5. Comparison of Braun and Roddin's Delay Estimates to AAD

PARAMETER	BRAUN AND RODDIN'S EQUATION 1	BRAUN AND RODDIN'S EQUATION 2
Correlation to actual average delay (r)	0.815	0.795
Average % difference in estimation	48.7	-46.9

With actual average delay as the response variable, theoretical delay and non-compliance are specified as explanatory variables to examine how they affect delay prediction. Correlation checks between the independent variables show that the non-compliance ratio variable (NCR) has a low positive correlation with Equation 1 (BR1) and a low negative correlation with Equation 2 (BR2). This implies that either BR1 or BR2 can be used with NCR in developing a delay model.

The actual average delay model using Equation 1 showed better results when compared to the model using Equation 2. Table 6 and 7 contains the estimation results and regression summary of the model developed here.

Table 6. Estimation Results of Sub-Model 2; Dependent Variable: AAD

N = 110	BETA	STD. ERROR OF BETA	B	STD. ERROR OF B	T(107)	P-LEVEL
Intercept			19.381	0.965	20.083	0.000
NCR	-0.606	0.030	-38.453	0.188	-20.458	0.000
BR1	1.129	0.030	0.931	0.024	38.143	0.000

The regression equation for actual average delay is hence:

$$AAD = 19.381 + 0.932(BR1) - 38.453(NCR) \qquad (Eq.5)$$

Knowing that $BR1 = \frac{(C-G)^2}{2C}$, and substituting it into the formulation , we have:

$$\mathbf{AAD = 19.381 + \frac{0.466(C-G)^2}{C} - 38.453(NCR)} \qquad (Eq.6)$$

where AAD = actual average delay of a group of pedestrians waiting to

enter the crosswalk, expressed in seconds;
C = the cycle length, in seconds
G = the length of pedestrian green time, in seconds
NCR = the ratio of non-complying pedestrians to total number of pedestrians entering a crosswalk

The t-statistic was used in analyzing the significance of each of the explanatory variables with respect to average delay. Without going into computational details, the t-statistic is basically the mean difference between the two groups, standardized by the variability in the data. Both variables had t-values that are beyond the critical range of ± 1.645 which means that the variability of the data between explanatory and response variable is about the same.

Table 7. Regression Summary for Dependent Variable: AAD

R	0.965
r^2	0.932
Adjusted r^2	0.930
F(2,107)	727.730
p-level	<0.000
Std. Error of Estimate	4.604

To interpret the direction of the relationship of average delay to the other variables, we look at the signs of the B coefficients. The coefficient of the non-compliance variable (NCR) is negative, thus implying there is a subsequent decrease in average delay as non-compliance increases. This agrees with the hypothesis that non-compliance has not been properly taken into account in Braun and Roddin's equation and thus may be responsible for the equation's overestimated values of delay.

Ideally, a model should explain all the original variability of the data with the variables specified. This model exhibited a high r-square value close to 1.0 indicating that the model fits the data very well. The low index of the p-level implies that the observed result is statistically significant.

6. SENSITIVITY ANALYSIS

Using Eq.6, the sensitivity of average delay to different variables was examined by first holding cycle time and green ratio constant, and then substituting different values of the non-compliance ratio into the equation. The range of non-compliance ratios used was from 0 to 1.0. The resulting values of actual average delay were then tabulated.

Figures 4 and 5 shows the outcome of various combinations of cycle time and green ratio. The lowest value of cycle length used was 60 seconds and the highest at 300 seconds increasing by intervals of 60 seconds. The range of green ratio is from 0.1 to 0.5, which is the usual time allotted for pedestrians.

Each square on the gridline represents an interval of 10 seconds of actual average delay along the y-axis and 0.1 of non-complian[illegible] represent various green ratios ranging from 0.1 (the topmost line) to 0.5 (the bottommost line).

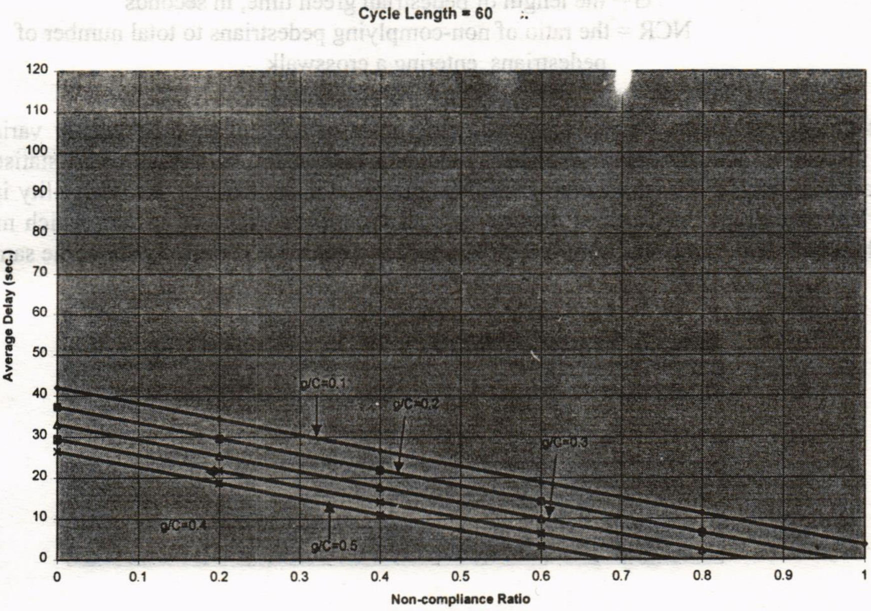

Figure 4. Sensitivity Curves for Cycle Length = 60 sec.

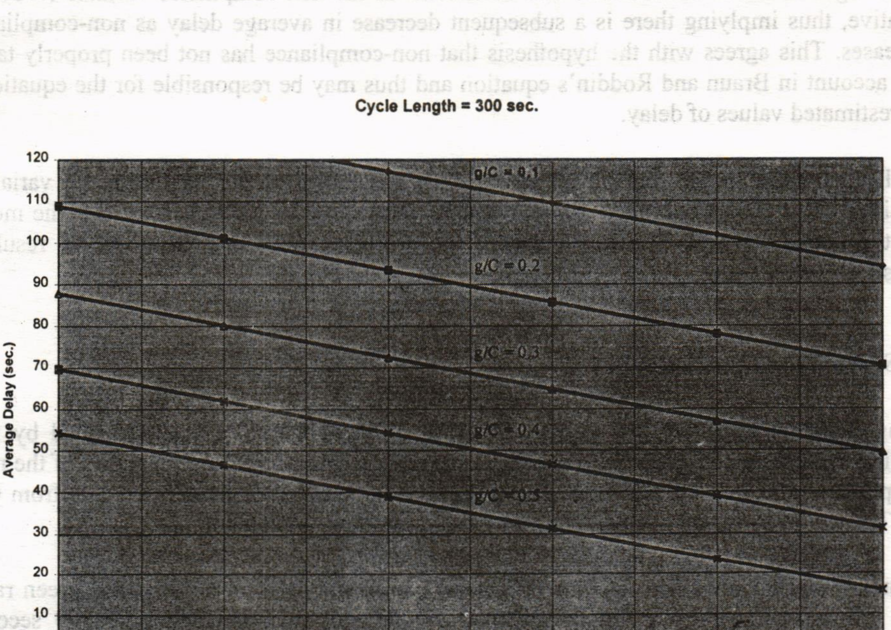

Figure 5. Sensitivity Curves for Cycle Length = 300 sec.

6.1 Delay Threshold for Total Compliance (DTTC)

After tabulating the results, it was found that for every combination of cycle time and green ratio, there corresponds a unique downward sloping curve depicting the trade-off between actual average delay and percentage non-compliance.

For the purpose of this study, the y-intercept of a particular line will be called the *delay threshold for total compliance (DTTC),* and is the point above which there are no signal violations. It is interpreted as the amount of delay that all pedestrians must be willing to accept to comply with the signal. Above this point non-compliance is always zero, meaning that if pedestrians are willing to be delayed for a period y that is beyond this point, then total compliance will be achieved. In the interval to the bottom of this point, pedestrians are accepting less delay than the required minimum to comply. As a result, observed values of delay falling within this interval will correspond to a positive value of non-compliance.

6.2 Zero Delay Non-compliance Ratio (ZDNR)

The x-intercept, on the other hand, is referred to as the *zero delay non-compliance ratio (ZDNR).* It is interpreted as the maximum expectable amount of non-compliance that results when everyone refuses to be delayed (willing to accept only zero delay). Although initial intuition seems to tell us that if everyone refuses to be delayed, then percentage non-compliance must be 100, this is not always correct. Given the maximum is at any value x, then (100-x)% of pedestrians at the intersection are actually entering the crosswalk when the pedestrian light is green. In short, a lower maximum can be a sign of more favorable conditions for pedestrians, such that most of the pedestrians wanting to cross are able to journey without much stopped delay.

6.3 Evaluating Signal Timing Measurements

Based on the figures, intersections with short cycles and which allot longer times for pedestrian movement will experience low degrees of non-compliance. As the DTTC moves closer to the origin, the minimum amount of time that pedestrians need to wait to comply with the signal becomes shorter. Shorter waiting times increase the likelihood that people will comply with the given signal and as a result, the ZDNR will be at lower levels, i.e. values closer to the origin. However, non-compliance will always be present as long as there are pedestrians who do not wait for this minimum time. The low degrees of non-compliance ratios for this combination also suggest that signal coordination is good, such that most pedestrians arrive at the crosswalk during the green signal.

Intersections with short cycles and low green ratios or long cycles and high green ratios, behave in almost the same manner. The DTTC shifts upwards implying longer waiting periods needed for total compliance to occur. Longer waiting times increase the likelihood that more people will violate the signal. Hence, the ZDNR is expected to be very close to the 100 mark.

For long cycles and large green ratios, the high ratios of non-compliance are due to the fact that pedestrians tend to get impatient waiting for the green signal and end up crossing before it is given. On the other hand, short cycles with small green ratios also result in high degrees of non-compliance and this may be because the green time given is too short to allow everyone to cross. Large ratios of non-compliance may also mean that signal coordination is poor. A zero value of delay translates to almost all pedestrians arriving during the red and disregarding the given signal indication.

At intersections with long cycles and low green ratios, non-compliance ratios are extremely high. This is because of two reasons: (1) the amount of green time is too short to accommodate all pedestrians; and (2) time that pedestrians have to wait for the green signal is too long. This oftentimes results in total disregard for any signal indication, as seen in the figure.

In the field, pedestrians are usually not conscious of how much time passes before he or she is able to cross. In fact, it may not be important to them whether or not they comply with the signal at all. Disorderly or uncontrollable pedestrian movement at an intersection could cause problems to vehicular traffic flow and pedestrian safety. Knowing the significance and values of the DTTC and ZDNR is thus advantageous when developing signal-timing measurements for an intersection because it will now be easier to determine the effects that specific combinations of cycle and green time have on pedestrian movement. In effect, we are taking pedestrian welfare and safety into account in the design process, and this ultimately results in signalized intersections that are not only motorist-centered but pedestrian-friendly as well.

7. CONCLUSIONS

Because non-compliance is an indication of an intersection's efficiency in accommodating pedestrians, it is imperative that it is considered whenever studies on pedestrian movement are made. While violation of traffic rules is partly due to a pedestrian's judgement (or lack thereof), the other factors which contribute to this event should also be known especially if these factors can be controlled.

This study analyzed several intersections according to the condition and availability of certain crosswalk variables and their corresponding effects on the propensity of pedestrians to violate the signal indications.

The first sub-model developed in this study describes how pedestrian signal non-compliance is affected by physical factors at a crosswalk. It has been found that pedestrian volume, crosswalk width, and pedestrian signals were significant explanatory variables for pedestrian non-compliance. The data had a relatively good fit ($r^2 = 0.661$) and other statistical tests show that there is a low probability of error in accepting the observed relation between the variables as valid.

Determining what variables have the greatest influence on signal violations at crosswalks will help designers focus on what aspects to improve. The model developed here tells us that non-compliance is greatly reduced by providing working pedestrian signals and wider crosswalk areas. With this in mind, crosswalks can be modified to minimize non-compliance and thereby increase pedestrian safety.

Delay is an indicator of the quality of pedestrian flow and is one of the major criteria in the development of level of service standards and thus the second sub-model showed how delay estimates could become more accurate by incorporating pedestrian non-compliance effects.

In modeling pedestrian delay, pedestrians are usually assumed to comply with signal indications. The second sub-model shed light on how Braun and Roddin's pedestrian delay equation could be modified by incorporating an adjustment term for non-compliance in order for it to be applicable for local conditions, where pedestrian violations are predominant. The resulting model showed a very high r-square value (r^2 =0.932), and other tests proved that the model is statistically significant.

With the development of a delay model which is representative of the prevailing pedestrian situation, this study lays the groundwork in the formulation of level of service design standards for local conditions. Using the model to examine pedestrian flow characteristics vis-à-vis crosswalk variables, optimal intersection conditions may be estimated and levels of service identified. These standards may then be used in the design or improvement of intersections that serve not only vehicles, but provide safer and more adequate passageways for pedestrians as well.

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