INCORPORATING NON-COMPLIANCE EFFECTS ON PEDESTRIAN DELAY AT SIGNALIZED INTERSECTIONS

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Abstract: Nineteen crosswalks in Metro Manila were surveyed and average pedestrian stopped delay was measured randomly during selected times of the day. These values of delay were compared with estimated delay obtained from three standard delay equations.

The delay equation which had best correlation and which overestimated average actual delay from the field was used in the rest of the study. Delay savings were computed by subtracting predicted delay from measured delay and regressed against the percentage of non-complying pedestrians. The delay savings-percentage non-compliance model showed an r^2 value of 0.917, which means that 91.7% of the variations in average delay savings is explained by non-compliance. Based on the results, an appropriate equation for pedestrian delay may be developed and will prove useful when evaluating the quality of pedestrian flow at signalized intersections.

1. INTRODUCTION

An accurate prediction of pedestrian delay is important when evaluating the quality of pedestrian flow at signalized intersections, especially if the density of pedestrians in these areas is high. Models of pedestrian delay are based on the assumption that pedestrians proceed only when the green signal is given. In the field, however, this is not the case as pedestrians will ignore the indicated pedestrian signal to minimize their own delay. This research was aimed at describing the relationship between the delay savings of pedestrians and their non-compliance. The results may prove useful in developing appropriate delay equations for pedestrians in the local setting, as well as in timing traffic signals for street networks.

Several formulas are used to compute for pedestrian delay. Braun and Roddin (1978) developed the following equation which assumes continuum flow, constant cycle length, no pedestrian actuation, and complete signal compliance:

$$d = \frac{(c - g)^2}{2c}$$

where: d = average stopped delay per pedestrian (sec.)
c = cycle length
g = duration of pedestrian green signal

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

$$d = \frac{F(c - g)^2}{2c}$$

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 (1991) 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 was used as if it were effectively green, as shown below:

$$d = \frac{[c - (g + 0.69A)]^2}{2c}$$

where A = duration of clearance or flashing red signal

While Virkler's study 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.

One of the better known formulas for delay at signalized intersections is the one developed by Webster. Although it is primarily used for vehicles, it operates in the same principle as Equation 1 and may also be applied when estimating pedestrian delay.

The first term of Webster's delay equation in the 1985 U.S. Highway Capacity Manual is often referred to as being the uniform delay component, as shown in the following equation:

$$d = \frac{c(1-\lambda)^2}{2(1-\lambda x)}$$

where: λ = g/c ratio (the proportion of the cycle that is effectively green)
x = the degree of saturation (the ratio of average number of arrivals/cycle to the maximum number of departures/cycle)

Since pedestrians almost never experience overflow delay and generally can enter the intersection on the first green signal, there is no need for the second and third term of Webster's full expression.

In the Philippines, it is often observed that pedestrians usually start crossing even 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.

2. SITE SELECTION AND FIELD STUDY

Data was collected from 19 crosswalks at 6 pre-selected signalized intersections in Metro Manila, specifically the cities of Pasay, Makati, Manila and Quezon City. 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.

These crosswalks were videotaped for a minimum of three cycles. All crosswalks 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 duration of cycle and green times,
(2) the total number of pedestrians using the crosswalk,
(3) the number of pedestrians who enter the crosswalk when there is a conflicting vehicular movement (referred to as "non-complying")
(4) the degree of saturation (ratio of average number of arrivals/cycle to the maximum number of departures/cycle during the green signal)
(5) the 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.

Table 1 summarizes the characteristics of the intersections surveyed in this study. The signal cycle lengths for most intersections were found to be longer than the U.S. HCM standard maximum of 180 seconds.

Table 1. Data Characteristics

Parameter	Mean	Median	Max.	Min.	Std. Dev.
Cycle length (sec.)	200	190	335	140	43.3
Green time (sec.)	75	70	160	30	28
Volume entering (per cycle)	33	28	86	7	20
% Non-complying (per cycle)	32.8	23.7	92.9	0	27.5
Degree of Saturation	0.8	0.8	0.97	0.5	0.1
Ave. stopped delay (sec.)	44.9	42	102.4	16.4	17.4

The crosswalks observed showed no definite pattern in volume, as some crosswalks had peak volumes during the mornings while others exhibited peaks in the afternoon.

Non-compliance ranged from 0 to 93%, the highest seen in areas where there are numerous obstructions along the crosswalk (e.g. loading and unloading vehicles) and in locations where pedestrians relied on traffic enforcers to be given the right-of-way. In some locations, it was observed that majority of pedestrians enter the crosswalk before the green signal is given, and continue to leave the curb even after the onset of the red signal.

3. MODELING APPROACH

3.1 Study Flow Diagram

Figure 1 shows the structure of the modeling approach. The flow chart starts with the comparison of delay estimates from the three theoretical equations to determine which equation is to be used in the rest of the study. Delay savings are then computed by subtracting predicted delay with actual delay and regressed against the percentage of non-complying pedestrians to determine the relationship between these two variables. Lastly, conclusions are drawn from the resulting model.

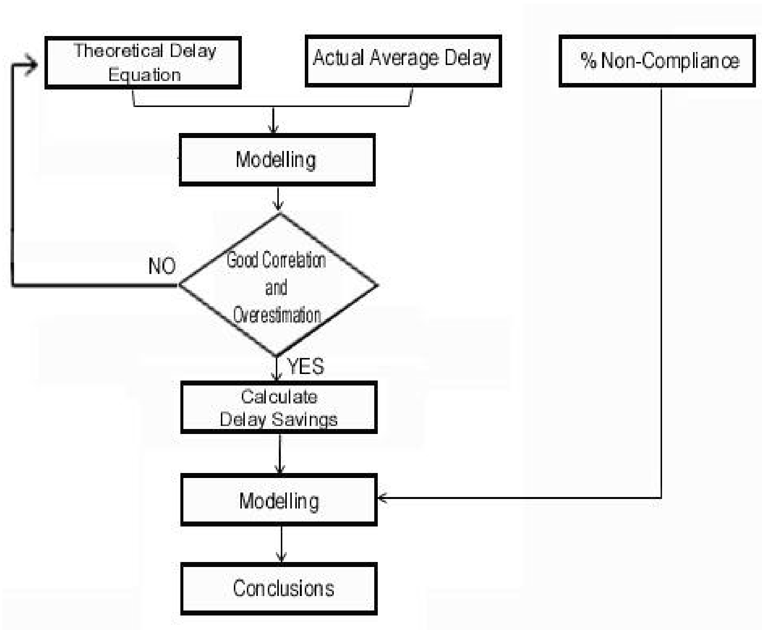


Figure 1. Modeling Framework

3.2 Selection of Delay Model

Before developing the relationship for delay savings and non-compliance, each of the theoretical equations for delay were compared to measured delay (from video) to determine which one gave the best estimates. For a conservative approach, the equation which overestimated delay (assuming complete compliance) was chosen over the others which underestimated it. By using delay estimates which are slightly higher than the actual delay, it is assumed that non-compliance has not yet been taken into account, and that this may be the reason behind the differences in delay.

First, delay was estimated by applying the signal timing data to Braun and Roddin's pedestrian delay equation for each of the 19 crosswalks. This equation assumes uniform flow and that pedestrians will only begin to cross at any time during the green phase. The estimates were compared to measured delay as shown in Figure 2. A significant correlation (r = 0.815) was found between the results. A perfect model would have all data points fall on the line with a slope of one. Instead most of the measured delays are greater than the predicted delays, with predicted delays underestimating the actual delay by an average of 9%.

This proves that this equation may oversimplify what is actually happening in the field and may be too simplistic for local conditions.

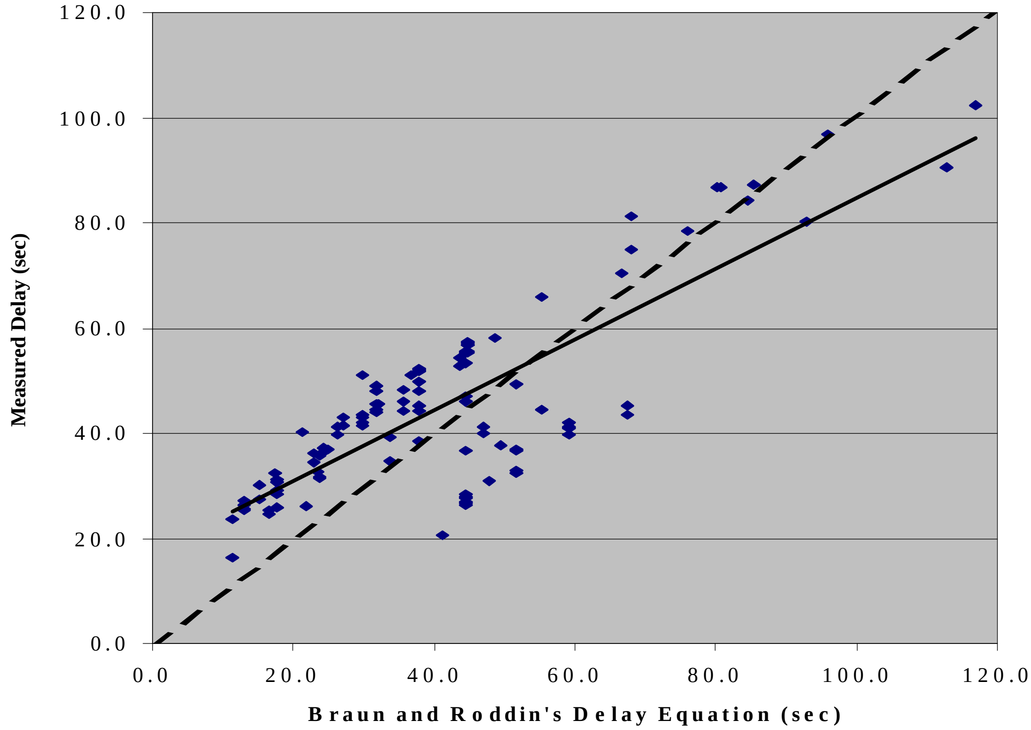
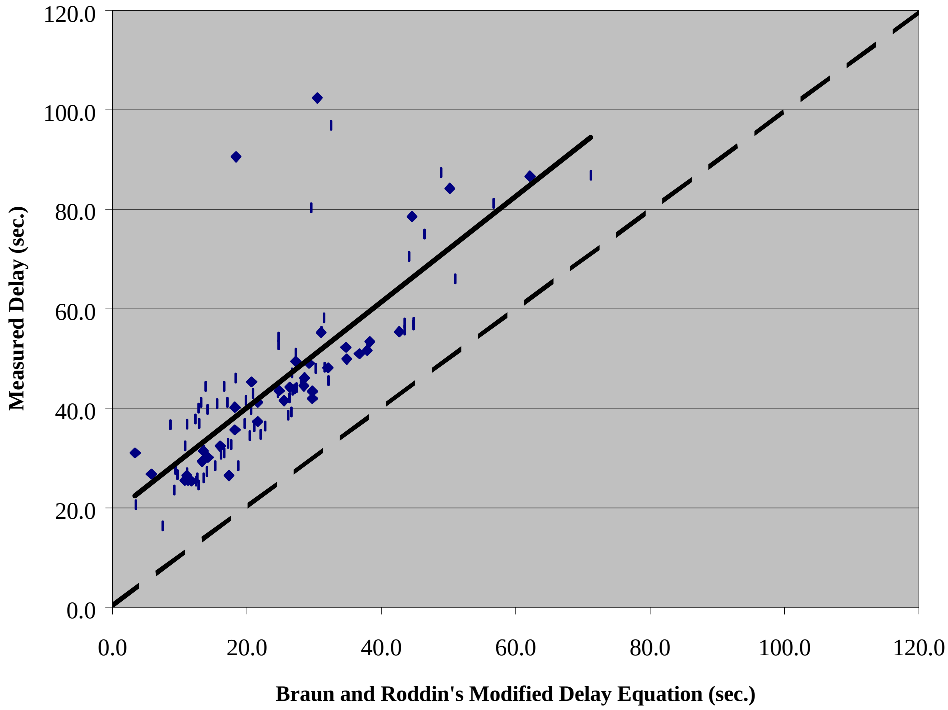


Figure 2. Measured Delay versus Braun and Roddin's Delay Equation

Predictions from Braun and Roddin's modified pedestrian delay equation were also compared to measured delay (**Figure 3**). This equation assumes that those who do not comply with the signal receive no delay. This equation gives a poor estimate for delay as the average delay prediction was 46.9% smaller than that measured and the correlation was weaker (r= 0.795).

Figure 3. Measured Delay versus Braun and Roddin's Modified Delay Equation



Lastly, measured delay was compared to delay derived using Webster's delay equation (**Figure 4**), which assumes complete compliance. This gives the best correlation (r = 0.833) with predicted delay averaging 29.4% larger than measured delay. This result agrees with the concept that some pedestrians reduce their own delay by violating the signal indication.

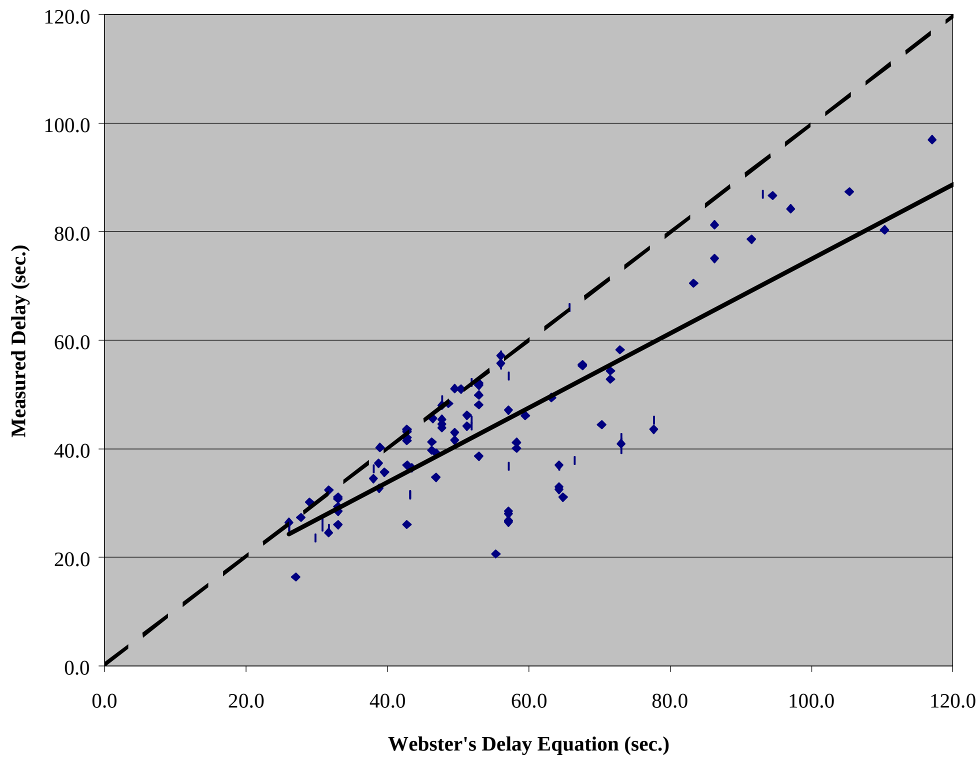


Figure 4. Measured Delay versus Webster's Equation

Table 2 provides a summary of results using the linear regression analysis between measured delay and delay estimates from each of the three equations.

Table 2. Comparisons of predicted to measured delay

Parameter	Braun and Roddin	Modified Braun and Roddin	Webster
Correlation to measured delay (r)	0.815	0.795	0.833
Average Percentage difference (%)	-9.0	-46.9	29.4

Webster's delay equation clearly satisfies the criteria in the selection of an appropriate pedestrian delay equation in that it overestimates pedestrian delay and gives the best correlation when compared to measured delay from the field. Therefore, Webster's equation was used in the next step.

3.3 Relating Pedestrian Delay Savings with Signal Non-compliance

The data were then examined to determine if non-compliance is responsible for the differences in theoretical and measured delay. Percentage non-compliance is computed by dividing the number of non-complying pedestrians/cycle to the total number of pedestrians/cycle and multiplying this ratio by 100. On the other hand, measured delay was subtracted from the delay estimates of Webster's delay equation to get delay savings (the amount of delay saved by pedestrians). This difference was then regressed against percentage of non-complying pedestrians (**Figure 5**).

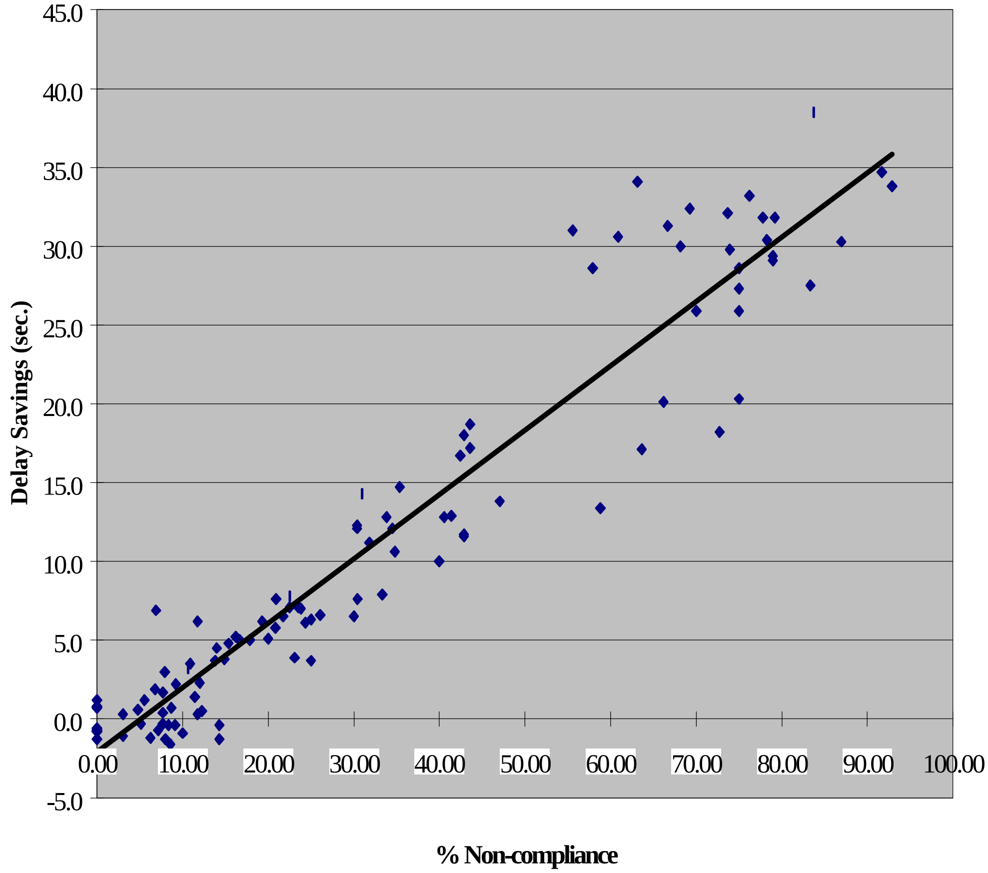


Figure 5. Delay savings - % Non-compliance Model

The model showed an r^2 value of 0.917, which means that 91.7% of the variations in average delay savings is explained by non-compliance. The relationship is as follows:

$$\mathbf{y = 40.862x - 2.1041}$$

where y = average delay savings (sec.)
x = the percentage of non-complying pedestrians using the crosswalk

The slope of the line (the rate at which average delay savings increases with respect to percentage non-compliance) is 40.862, which implies two things. First, the greater the degree of non-compliance, the greater the delay savings. Consequently, the delay measured will be significantly smaller than the delay predicted by the theoretical equation. Second, people tend to move in groups at crosswalks, such that if one decides to violate the indicated signal and enter the crosswalk prematurely, the others are sure to follow; resulting in high average delay savings for the whole group.

4. CONCLUSIONS

Having accounted for delay savings using non-compliance as the primary explanatory factor, this study has reached the following conclusions:

(1) Braun and Roddin's pedestrian delay equation is over-simplistic because it assumes that signal timing measurements are the only determining factors for delay. Since it underestimates delay by an average of 9%, it is not advisable to apply this equation to local conditions. Likewise, the modified standard pedestrian delay equation, gives a poor estimate for pedestrian delay, as the correlation was weaker and the average delay prediction was 46.9% smaller than that measured.

(2) Webster's uniform delay equation (Equation 3) was found to be the best formula for local conditions because it overestimates delay by assuming complete compliance. This gives the best correlation with predicted delay averaging 29.4% larger than measured delay. This result agrees with the concept that some pedestrians reduce their own delay by violating the signal indication, and this made it compatible with the planned modeling approach.

(3) Webster's formula was used as ideal delay, and delay savings were calculated based on it and actual measured delay. Then the authors developed a good model with delay savings apparently explained by pedestrian signal non-compliance ($r^2 = 0.917$).

(4) The model shows that as the degree of non-compliance increases, average delay savings also increases, implying that in a group waiting to cross an intersection, if one decides to violate the indicated signal and enter the crosswalk prematurely, the others are sure to follow. This results in high average delay savings for the whole group.

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