PEDESTRIAN CROSSING SPEED MODEL USING MULTIPLE REGRESSION ANALYSIS

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Abstract: Pedestrian signal allocates the appropriate time for pedestrian to cross safely a place where vehicle and pedestrian conflict are great. This study intends to formulate a model that will be used in determining the pedestrian speed using the available data that can be found in an actual situation in a signalized crosswalk. Four crosswalks will be observed to gather necessary data to come up with an appropriate model that can be used in other studies with regards to pedestrians. Speed-Density relationship will also be observed to find out whether the considered crosswalk adheres to the basic concept of Speed-Density relationship that the Highway Capacity Manual stated. These data includes: pedestrian volume, pedestrian crossing time, crosswalk dimension and actual crossing cycle time. After a thorough research and experimentation, the researcher found out several factors that may affect the speed of the pedestrians and the researchers came to conclusion that it is not merely by density. The dimension of the crosswalk affect the speed in terms that when the length of the crosswalk is lengthened; the tendency is to increase their speed as not to be caught up by the movement of traffic. In the course of our research, we conclude that the presented variables are not enough to explain the variation on speed. The researchers had formulated a model to predict the pedestrian signal but due to its low coefficient of determination, the researchers conclude that the model may not predict the correct pedestrian speed located outside the study area.

Key Words: pedestrians, crosswalks, variables, model

1. Introduction

Pedestrians can be considered as a basic element of transportation. All transport related travel and journeys must begin and end in walking. With such importance, this has been an unnoticeable factor in the design and planning of transportation system. The need to provide a safe, secure and convenient way of traveling is the main objective of a transport planner, thus giving importance to pedestrians is one way to do it.

The presence of crosswalks or pedestrian lanes is considered a calming effect to the vehicular traffic, but this could be a source of congestion if not handled correctly. One factor to minimize vehicular delay is to provide an equal signalization to cater both motorist and pedestrians.

The pedestrian crossing time serves as a constraint on the green time allocated to each phase of a cycle. Pedestrians can safely cross an intersection as long as there are not any conflicting movements occurring at the same time. (Permitted left and right turns are common exceptions to this rule.) This allows pedestrians to cross the intersection in both the green interval and the intergreen interval. Thus, the sum of the green interval and the intergreen interval lengths, for each phase, must be large enough to accommodate the pedestrian movements that occur during that phase.

At this point, two separate conditions arise. If you have an intersection in which the pedestrian movements are not assisted by a pedestrian signal, you need to make sure that the green interval that you provide for vehicles will service the pedestrians as well.
If, on the other hand, you plan to provide a pedestrian signal, you need to calculate the pedestrian crossing time as described below. This will not only give you the information you need to program the pedestrian signal, but it will also allow you to find the minimum green interval for your vehicular movements as well.

It is observed that the calculation of pedestrian crossing time is dependent to vehicular signal. This type of formulation does not consider the different important factors that can be considered in time allocation. Some major factors that can be considered are the geometric design of the crosswalk and the speed profile of the pedestrians who uses the crosswalk facilities.

Increased awareness of environmental problems and the need for physical fitness encourage the demand for provision of more and better pedestrian facilities. To provide better pedestrian facilities, the appropriate standard and control of the facilities need to be determined. To decide the appropriate standard and control of pedestrian facilities, pedestrian studies, which consist of pedestrian data collection and pedestrian analysis, need to be done. One of the objectives of the pedestrian studies is to evaluate the effects of a proposed policy on the pedestrian facilities before its implementation. The implementation of a policy without pedestrian studies might lead to a very costly trial and error due to the implementation cost (i.e. user cost, construction, marking etc.). On the other hand, using good analysis tools, the trial and error of policy could be done in the analysis level. Once the analysis could prove a good performance, the implementation of the policy is straightforward. The problem is how to evaluate the impact of the policy quantitatively toward the behavior of pedestrians before its implementation.

For this reason, the researchers aim to enumerate and explain the variables that can be a big player in the prediction of pedestrian speed profiles.

2. Framework
2.1. Conceptual Framework

The pedestrian speeds are could be affected by the crosswalk dimensions, existing signal timing, pedestrian volume and vehicular movement which can be used in the design of more efficient crosswalk signalization. Pedestrian signal timing is directly affected by the speed profile of the people that utilizes the crosswalk.

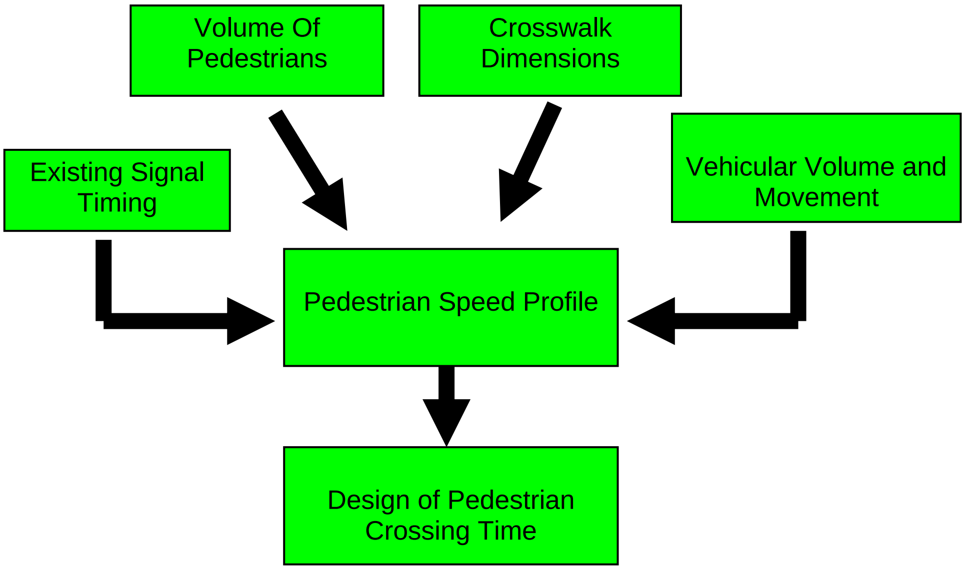

Fig. 2.1 Conceptual Framework

2.2 Theoretical Framework

"The call for more walkable, livable and accessible communities has seen walking as an indicator species for the health and well being of a community. People want to live and work in places where they can safely and conveniently walk and not always have to deal with worsening traffic congestion, road rage and fight for a walking space… … The challenge for transportation planners, highway engineers and pedestrian user groups, therefore, is to balance their competing interest in a limited amount of right-of-way and to develop a transportation infrastructure that provides access for all, a real choice of modes, and safety in equal measure for each mode of travel"

U.S. Department of Transportation

3. Main Problem

It was observed that along Aurora Blvd. and Ramon Magsaysay Ave. the walk phases are of fixed time. Fixed time in a sense that the time allotted for walk phase is the same all throughout the day. The time allotted for the walk phase is not actuated to the number of pedestrians. This can cause accidents because there are still pedestrians on the crosswalk when the green phase for vehicles is in effect.

4. Objectives

A. To create a model to predict the pedestrian speed profile in a certain crosswalk.
B. To enumerate the different variables that could affect the speed of a pedestrian.

5. Scope and Limitation

Four crosswalks with conventional pedestrian signal were observed. The crosswalks chosen are along an arterial road, Ramon Magsaysay Avenue and Aurora Boulevard. Pedestrians are of varying ages and gender, but mostly students due to the proximity to university and colleges. This paper only discussed the effects of variables that can be observed in a crosswalk and disregarded the effects caused by vehicular traffic. The researchers assume a minimal to no vehicle to pedestrian interaction due to the reason that vehicles follow their own signal for each selected signalized intersection.

6. Methodology

6.1 Research Framework

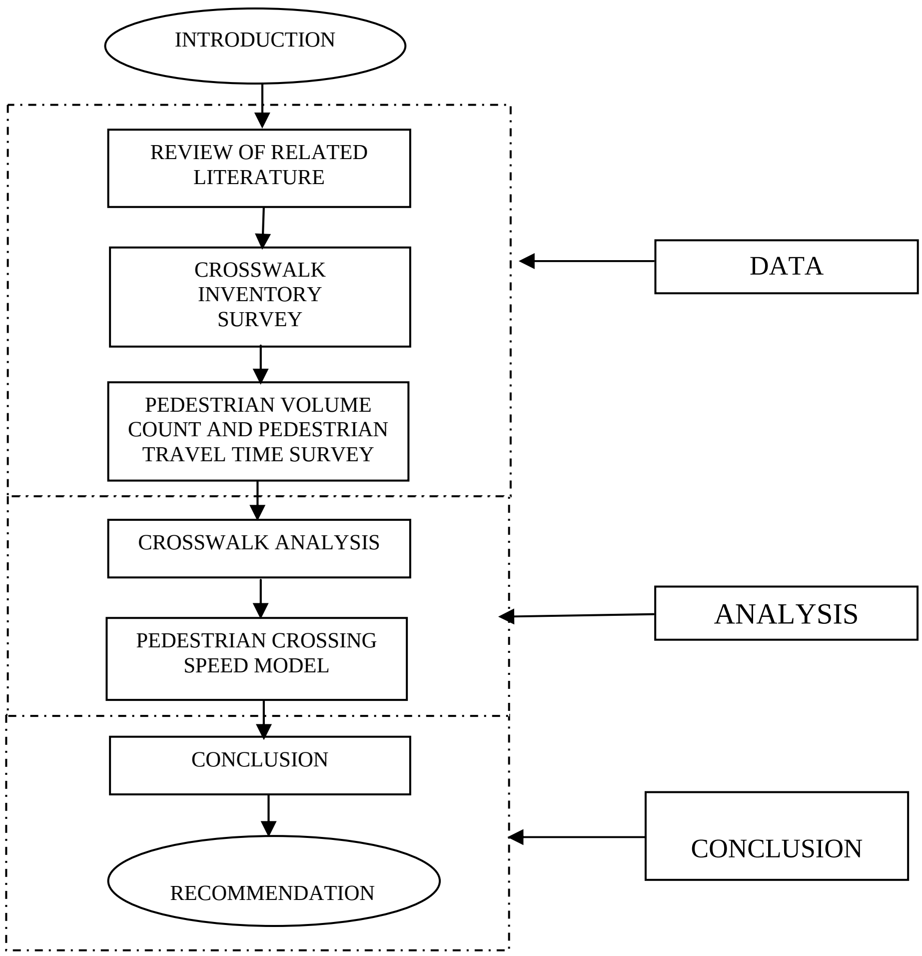

Fig. 6.1 Research Framework

Review of essential literature and studies were the first phase of this study to be able to come up with proper concept of the study. After the necessary research about the background of the study and formulating the framework, data gathering were carried out. Survey will be conducted in the form of crosswalk inventory survey, pedestrian volume survey and pedestrian travel time survey. From this basic data, other variables were computed and enumerated. Multiple Regression Analysis was used in treating this data to create a model that accommodated the acquired data. XLSTAT 2008 was used to aid the computation. Conclusion and Recommendation was took place after the analysis has been performed.

6.2 Criteria for Selecting Crosswalk

1. All crosswalks should be near a school or any educational establishment.
2. Must have a functional signalization in the time of the survey.
3. Should recognizable as a crosswalk and must be of ladder or zebra type.
4. Must be located at an intersection or junction.
5. Must have existing median or refuge island.

6.3. Statistical Analysis of Data

For this study, the statistical method that were used are Analysis of Variance (ANOVA) in order to verify the significance and relevance of the variable that we've gathered and Multiple Linear Regression Analysis to analyze all acquired variables and to create the appropriate model for the study. XLSTAT 2008 was used for the computation.

6.4. Formulae Used

SPEED

$$S = \frac{Lc}{ct} \quad \text{- (Equation 1)}$$

where:

S = speed
Lc = length of crosswalk
Ct = actual crossing time

FLOW

$$q = \frac{(Wv \;/\; G)}{Wc} \quad \text{- (Equation 2)}$$

where:

q = theoretical flow in ped/m/min
Wv = volume of walk ohase
Wc = Crosswalk width

DENSITY

$$k = \frac{Wv}{Ac} \quad \text{- (Equation 3)}$$

where:

k = density

Wv = volume of pedestrian
Ac = area of crosswalk

NON COMPLIANCE RATIO

$$NCR = \frac{Vt - Wv}{Vt}$$ - (Equation 4)

where:
NCR = non compliance ratio
Vt = total volume
Wv = volume in walk phase

7. Analysis of Crosswalk

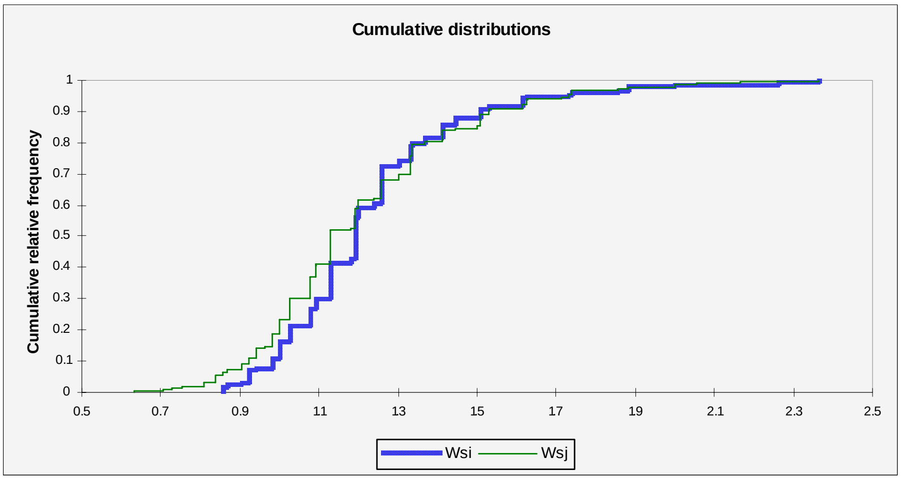

Fig. 7.1 – Cumulative frequency curve of crossing speeds taken at all crosswalks on i and j direction

TABLE 7-1 - 15th and 85th percentiles on each direction of all crosswalks

Direction	mean	standard deviation	15th percentile	85th percentile
i	1.226	0.241	1.000	1.413
j	1.203	0.269	0.983	1.444

As observed from this tables and figures, the values for the 15th percentile for speed are slightly low from the recommended speed of 1.2 m/s (AUSTROADS 1995). only the speed profile in Lacson gave a close speed profile of 1.13 m/s and 1.24 m/s for i and j direction. This gives us the impression that crosswalks along R. Magsaysay are not ideal as per compared to the crosswalks in other countries. But still all crosswalks displayed a reasonable speed profiles.

8. Design speed profiles

TABLE 8-1 - Corresponding properties of crosswalk

Crosswalk	Length (m)	Width (m)	Green time (s)	Cycle time (s)

CCP	22.6	2.4	25	106
Stop & Shop	22.6	2.4	12	179
Lacson	26	2.4	26	195
Gilmore	12	2.4	13	81

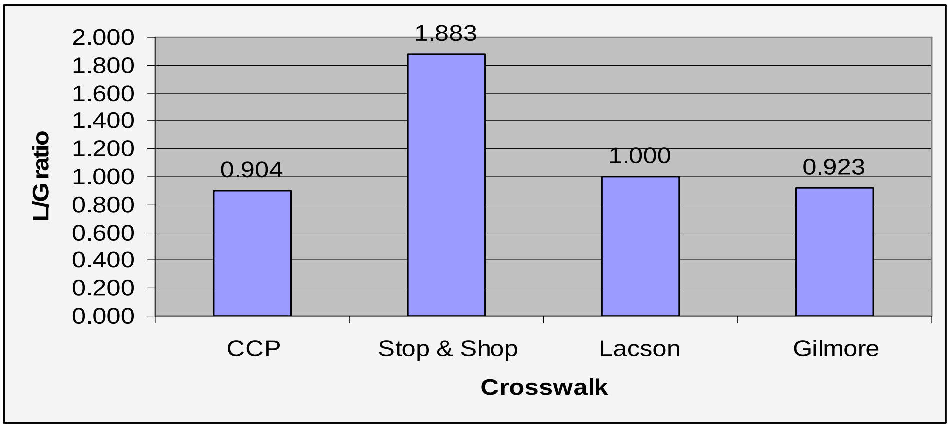

Fig. 8.1 – Column graph of length –green time ratio per crosswalk

Fig. 8.1 shows the length – green time ratio per each crosswalk. Length – green time ratio can also be interpreted as the expected speed profile in each crosswalk and is expressed as m/s. It is observed that in Stop & Shop crosswalk the expected pedestrian speed is almost 1.9 m/s which is too fast for walking and is considered almost running or jogging. It shows that the mean speed for the said crosswalk is only 1.2 m/s which is significantly low from its expected speed profile. This might give us the idea that in the design of this crosswalk, there is no provision for the elderly and the disabled. This also implies that the allocation of crossing times is not dependent to the length of the crosswalk.

9. Non Compliance Ratio

Traditional pedestrian signals typically operate in three phases, "WALK", "FLASHING DON'T WALK" and "STATIONARY DON'T WALK". The new pedestrian countdown traffic signals also operate in the same three phases. However, during the second "FLASHING DON'T WALK", phase, the signal displays a countdown of the remaining time (in seconds), along with the "FLASHING DON'T WALK" sign, indicating how much time is remaining before the lights change. Consequently, pedestrians are better able to decide if they wait for the next walk cycle or have time to get across. Theoretically, the display of remaining time gives better information to pedestrians and consequently reduces the potential for conflicts between pedestrians and vehicles at street intersections and crosswalks.

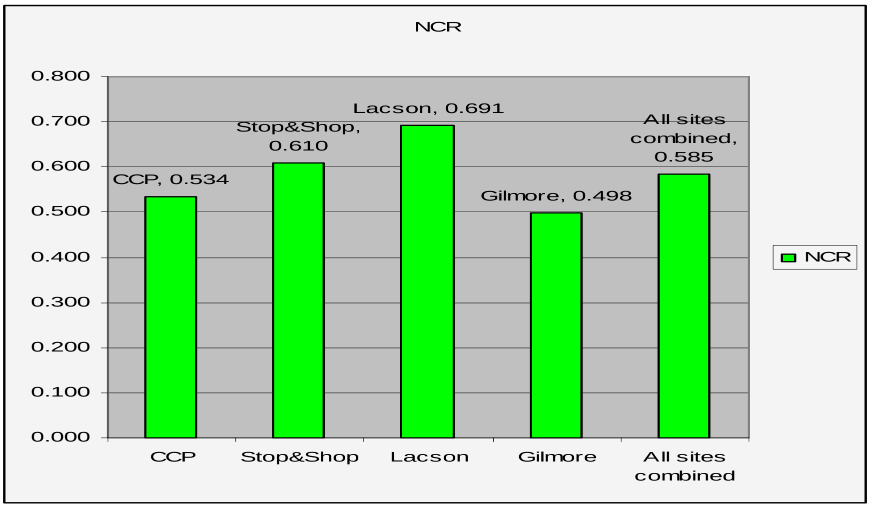

Fig. 9.1 – Non-Compliance Ratio for each crosswalk and all sites combined.

TABLE 9-1 – Corresponding volumes and non-compliance ratio for all crosswalks

Crosswalk	volume on walk phase	volume on non-walk phase	total cycle volume	NCR
CCP	2228	2553	4781	0.534
Stop&Shop	1421	2218	3639	0.610
Lacson	629	1406	2035	0.691
Gilmore	334	332	666	0.498
All sites combined	4612	6499	11111	0.585

Fig. 9.1 and **Table 7-1** show that there is a significant level of non-compliancy at each crosswalk. An average of 0.60 is observed for all crosswalks, this implicates that more than half of the population doesn't understand the meaning of the indication displayed on the signals. This may also indicate that most of the pedestrians don't have any regards to the traffic rules. Lacson and Stop & Shop crosswalks have the highest number of non-compliancy thus may explain the high value of speed profile and the low value of density.

10. Relationships between Variables

In this section we shall discuss the relationship of speed to the other variables such as length, area, green time, cycle time, volume, and density. We assume that all relationships are linear, and by these comparisons, we can already assume the sign (positive or negative) of the variables.

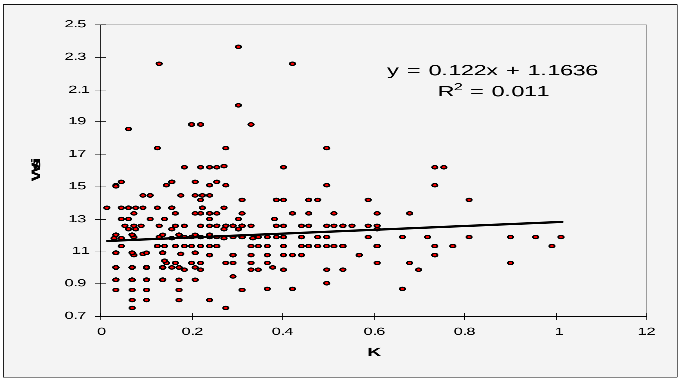

Fig. 10.1 – Linear relationship of walking speed in i direction (Wsi) to the total density (K).

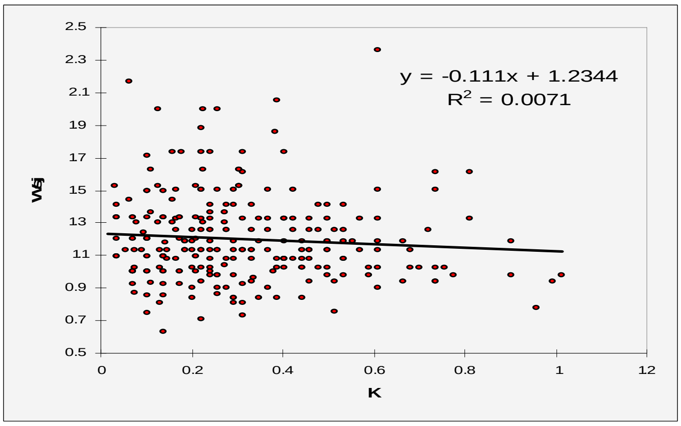

Fig. 10.2 – Linear relationship of walking speed in j direction (Wsj) to the total density (K).

In theory, the relationship of speed to the density is linear. Density is inversely proportional to the speed, as the density increases, the speed decreases. It is shown in **Fig. 10.1 and Fig. 10.2** that this relationship is not entirely attained. The slope of the first graph is positive while the second graph is negative which indicates that the ideal relationship for speed and density is not met. More importantly, the r^2 of the equation is too far low which gives us the impression that there is a small correlation between the two. We can now say that the density per crosswalk per phase is not the only factors that to be considered in predicting the value of speed.

In line with these, we would like to try a variation of the relationship by separating the density according to its direction.

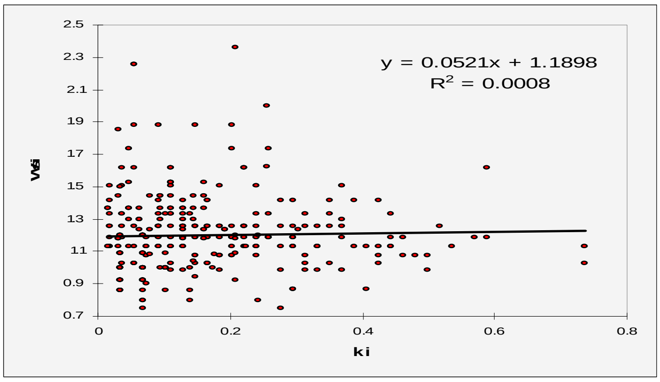

Fig. 10.3 – Linear relationship of walking speed in i direction (Wsi) to the total density in i direction (ki).

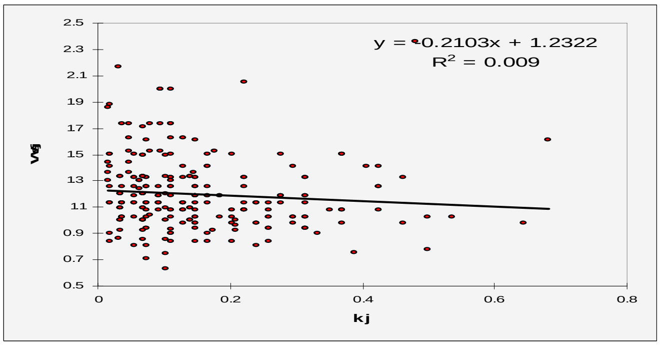

Fig. 10.4 – Linear relationship of walking speed in j direction (Wsj) to the total density in j direction (kj).

There is no significant change in the graph of speed-density relationship. It is observed that the r^2 for each graph became lower than the previous. The graph maintained their as sign as the previous which means we cannot clearly estimate its sign. We shall prefer a negative slope for each variable for the reason that the Fig. 10.4 attained a higher r^2. As observed in the previous graphs, there is a wide dispersion of samples which can indicate that there is no definite pattern for speed and other variables are present that has an effect to pedestrian speed.

In the next part, we would like to try different variables and see how it affects speed.

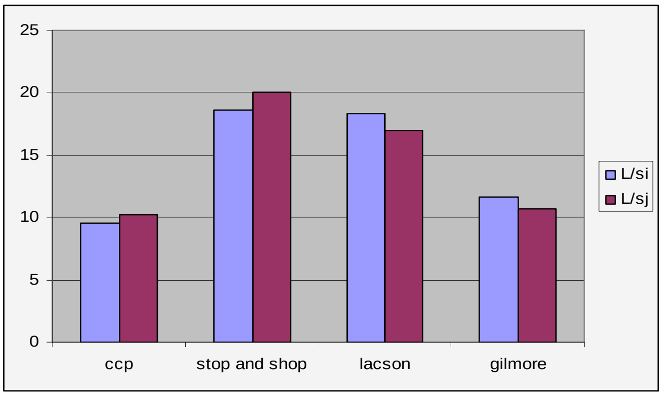

Fig. 10.5 – Graph of length-mean speed ratio per crosswalk

Shown in Fig. 10.5 is the ratio of length to mean speed ratio or mean travel time expressed in seconds. It is observed that the time it takes to cross a given crosswalk is relative to the length of the crosswalk.

TABLE 10-1 – Corresponding mean speed and crosswalk length for all crosswalks

crosswalk	mean speed on i-direction	mean speed on j-direction	length
ccp	1.254	1.178	12
stop and shop	1.213	1.126	22.6
lacson	1.419	1.531	26
gilmore	1.032	1.123	12

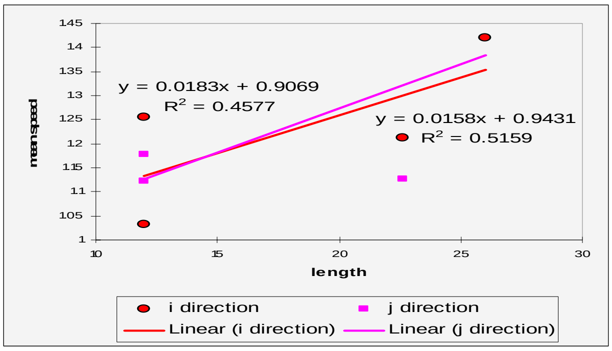

Fig. 10.6 – Linear relationship of mean walking speed to the length of the crosswalk.

The linear relationship of mean speed to the length bears a positive slope which means as the length increases the tendency of the pedestrians are to hasten their steps as not to be caught up by movement of vehicles.

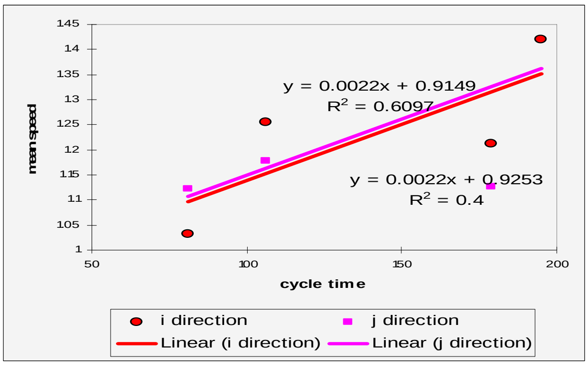

Fig. 10.7 – Linear relationship of mean walking speed to the cycle time of the crosswalk.

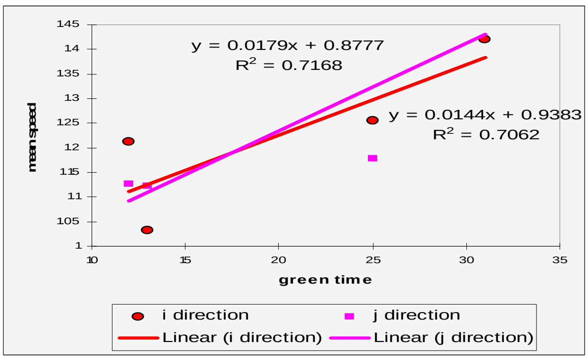

Fig. 10.8 – Linear relationship of mean walking speed

to the green time of the crosswalk.

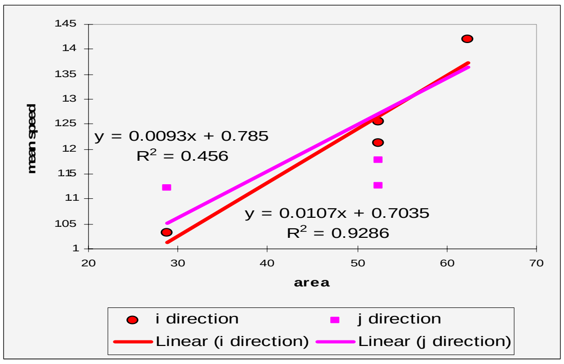

Fig. 10.9 – Linear relationship of mean walking speed to the area of the crosswalk.

We expect the sign of the cycle time, green time, and area to be a positive sign as displayed in **Fig. 10.7. Fig. 10.8. and Fig. 10.9 respectively.**

11. Model Estimation

In this section, we would estimate the variables that might have an effect in the prediction of speed. In the first model, referred to as MODEL1 we would assume that:

Ws = f (length (Lc), density along i direction (ki), density along j direction (kj))

These are the following result:

TABLE R-1: Results of the multiple regression analysis for model 1.

Summary of the variables selection (Variable Ws):

No. of variables	Variables	MSE	R^2	Adjusted R^2
1	Lc	0.048	0.185	0.175
2	Lc / ki	0.046	0.214	0.205
3	Lc / ki / kj	**0.046**	0.215	0.205

The best model for the selected selection criterion is displayed in blue

Goodness of fit statistics (Variable Ws):

Observations	246.000
Sum of weights	246.000
DF	242.000
R^2	0.215
Adjusted R^2	0.205

Analysis of variance (Variable Ws):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	3	3.076	1.025	22.114	< 0.0001
Error	242	11.221	0.046		
Corrected Total	245	14.297			

Computed against model Y=Mean(Y)

Model parameters (Variable Ws):

Source	Value	Standard error	t	Pr > |t|

Intercept	0.725	0.067	10.888	< 0.0001
Lc	0.027	0.003	8.097	< 0.0001
ki	-0.308	0.106	-2.914	0.004
kj	-0.052	0.114	-0.459	0.646

Equation of the model (Variable Ws):

Ws = 0.725 + 0.027*Lc - 0.308*ki -0.052*kj

Table R-1 shows that there a small coefficient of determination which is $r^2 = 0.215$. This means that this model explains only 21.5% of the whole variation of speed.

The computed F-value of 22.114 is greater than the critical F, Fc = 2.65 (Table 5, Elementary Statistics for Business and Economics, 1996, pp.527 – 530), which means that this model is significantly contributing in explaining the variation of speed.

In the second model, MODEL 2, we assume that:
Ws = f (length (Lc), flow along i direction (qi), flow along j direction (qj))
The results are as follows:

TABLE R-2: Results of the multiple regression analysis for model 2.

Summary of the variables selection (Variable Ws):

No. of variables	Variables	MSE	R²	Adjusted R²
1	Lc	0.048	0.185	0.175
2	Lc / qi	0.046	0.212	0.202
3	Lc / qi / qj	**0.047**	0.212	0.202

The best model for the selected selection criterion is displayed in blue

Goodness of fit statistics (Variable Ws):

Observations	246.000
Sum of weights	246.000
DF	242.000
R²	0.212
Adjusted R²	0.202

Analysis of variance (Variable Ws):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	3	3.026	1.009	21.653	< 0.0001
Error	242	11.272	0.047		
Corrected Total	245	14.297			

Computed against model Y=Mean(Y)

Model parameters (Variable Ws):

Source	Value	Standard error	t	Pr > |t|
Intercept	0.722	0.067	10.819	< 0.0001
Lc	0.026	0.003	8.001	< 0.0001
qi	-0.182	0.069	-2.614	0.010
qj	-0.009	0.078	-0.122	0.903

Equation of the model (Variable Wsi):

Ws = 0.722 + 0.026*Lc - 0.182*qi - 0.009*qj

Table R-2 shows the result of the second model. Although the values for r^2, F and p do not deviate greatly from the first model, it is established that the first model has a better fit.

In the third model, MODEL 3, we assume that:

Ws = f (length (Lc), volume along i directin (Wvi), volume along j directin (Wvj), green time (G))

The results are as follows:

TABLE R-2: Results of the multiple regression analysis for model 3.

Summary of the variables selection (Variable Ws):

No. of variables	Variables	MSE	R^2	Adjusted R^2
1	Lc	0.048	0.185	0.171
2	Lc / Wvi	0.046	0.213	0.200
3	Lc / Wvi / G	0.046	0.217	0.204
4	Lc / Wvi / Wvj / G	**0.047**	0.218	0.205

The best model for the selected selection criterion is displayed in blue

Goodness of fit statistics (Variable Ws):

Observations	245.000
Sum of weights	245.000
DF	240.000
R^2	0.218
Adjusted R^2	0.205

Analysis of variance (Variable Ws):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	4	3.114	0.779	16.735	< 0.0001
Error	240	11.165	0.047		
Corrected Total	244	14.279			

Computed against model Y=Mean(Y)

Model parameters (Variable Ws):

Source	Value	Standard error	t	Pr > |t|
Intercept	0.691	0.068	10.097	< 0.0001
Lc	0.025	0.004	5.860	< 0.0001
Wvi	-0.005	0.002	-2.660	0.008
Wvj	-0.001	0.002	-0.432	0.666
G	0.003	0.003	1.072	0.285

Equation of the model (Variable Ws):

Ws = 0.691 + 0.025*Lc - 0.005*Wvi - 0.001*Wvj + 0.003*G

Table R-3 shows the result of the third model. Although the value of coefficient of determination, r^2 =0.218 is slightly grater than the value for the first model, r^2 = 0.215, the F value for the third model, F=16.735 is significantly low compared to the F value of the first model, F=22.114.

11.1. Model Selection

After determining the possible variables and its relation to speed, we select MODEL 1 as our final model.

Equation of the model (Variable Ws):

$$Ws = 0.725 + 0.027*Lc - 0.308*ki - 0.052*kj$$

12. Conclusions

This paper aims to improve the pedestrian flow on crosswalks by analyzing several crosswalks. To achieve this goal, the researchers develop a model that may predict the speed of the pedestrians. Along this research, several facts have been taken into account.

a. There are a significant number of pedestrians who do not clearly understand the meaning conveyed by the pedestrian signalization. About 60% or 6 out of 10 pedestrians do not follow the pedestrian signals.
b. The pedestrian speed profile in all four crosswalks is slightly lower than the recommended speed profile.
c. The density is not the only factor that affects the speed of the pedestrians. There may be so much more and are not discussed in this paper such as delay, uncomfortability, vehicle movement, vehicle speed, queuing, topology, destination, path, and time of signalization (semi actuated, fully actuated, CPS).
d. The signal timing in these crosswalks is not affected by the length of the crosswalk. Even if the crosswalk length is increased, the signal timing does not necessarily be increased.

13. Recommendations

a. Additional model for obstructions and wall avoidance of the microscopic pedestrian simulation model is suggested to perform a better capacity analysis.
b. Integration of pedestrian flow in planning and design.
c. Inclusion of pedestrians to the education system in terms of new subjects discussing pedestrian flow and crowd movement.
d. Use of fully actuated signals for pedestrians and of countdown pedestrian timers to minimize vehicular conflicts and non compliancy.
e. Improvement of the automatic video data collection toward the occlusion problem is highly recommended to enhance the performance of the system for higher pedestrian traffic density.
f. Alternative research or survey methodology such as instantaneous speed and density data collection.
g. Further studies on pedestrian flow which can include:
    1. Larger study area that can include all metro manila.
    2. Analysis of both signalized and unsignalized crosswalks.
    3. Analysis for both one-way and two-way pedestrian lane.
    4. Inclusion of model variables such as:
        i. delay
        ii. pedestrian generators (schools, offices, railway station, malls)
        iii. pavement markings

iv. dissipation time
v. vehicular movement and speed
vi. pedestrian interaction
vii. queuing time

5. pedestrian analysis using:
   i. Benefit cost cellular model
   ii. Cellular automata model
   iii. Magnetic force model
   iv. Social Force model
   v. Queuing network model

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