PEDESTRIAN LEVEL OF SERVICE MODEL FOR CROSSWALKS AT SIGNALIZED INTERSECTIONS

BASIL DAVID DANIEL
CHOONG SIEW LAY
KAMARUDIN AMBAK
AMBAK EZREE ABDULLAH

10

PEDESTRIAN LEVEL OF SERVICE MODEL FOR CROSSWALKS AT SIGNALIZED INTERSECTIONS

Basil David Daniel, Choong Siew Lay, Kamarudin Ambak, Mohd. Ezree Abdullah
Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia,
Batu Pahat, 86400
E-mail: basil@uthm.edu.my, kamardin@uthm.edu.my, ezree@uthm.edu.my

ABSTRACT: A study was undertaken to develop a pedestrian level of service (P-LOS) model for crosswalks at signalized intersections for the purpose of improving the serviceability of crosswalks at signalized intersections and identifying factors which affect pedestrian crossing at these locations. The factors fall into three main categories, which are pedestrian factors, crosswalk factors and roadway factors. The P-LOS model was developed using multiple linear regression analysis. From this study, it was found that pedestrian crossing time, pedestrian flow, pedestrian delay, crosswalk surface condition , crosswalk marking, pedestrian holding area and roadway width were significant in the development of the P-LOS model, and therefore influenced the movement of pedestrians at signalized intersections.

Keywords: pedestrian, level of service, crosswalk, signalized intersections

1 INTRODUCTION

Non-motorized transportation such as cycling and walking are becoming increasingly popular as a mode of transport and recreation because it provides many benefits such as reduced traffic congestion, user savings, road and parking facility savings, economic development and a better environment.

Pedestrians are a part of most roadway environments, therefore attention must be paid to their presence in rural as well as urban areas. However, due to the demands of vehicular traffic in congested urban areas, it is often extremely difficult to make adequate provisions for pedestrians. Therefore, this research may assist transport engineers in planning and designing pedestrian facilities, especially crosswalks at urban intersections.

1.1 Background of Study

This research was carried out ultimately to develop a pedestrian level of service (P-LOS) model which takes into account the factors which influence pedestrians' perception of safety and comfort and thus help provide higher LOS for pedestrian crosswalks at signalized intersections.

In order to develop the P-LOS model, a statistical method called multiple linear regression analysis was used. Through this analysis, an algorithm which relates P-LOS with pedestrian, crosswalk and roadway factors.

The study was conducted in several towns in Johor, Malacca and Kedah. A total of thirty signalized intersections were selected as samples for the analysis. The list of locations studied is shown in Table 1.

Table 1. List of study locations

State	Location of Study
Johor	Jalan Kluang (Parit Raja), Jalan Kluang (UTHM), Jalan Omar, Jalan Mohamad Khalid, Jalan Wawasan Utama, Jalan Rahmat, Jalan Ibrahim, Jalan Johor, Jalan Bahru, Jalan Batu Pahat, Jalan Yahya, Jalan Arab, Jalan Bentayan, Jalan Abdullah, Jalan Salleh, Jalan Jorak, Jalan Jabar, Jalan Temenggung Ahmad, Jalan Muar, Jalan Solok
Malacca	Jalan Merlimau (Batu Gajah), Jalan Merlimau (Bandar Melaka)
Kedah	Lebuhraya Darul Aman, Jalan Mergong, Jalan Sultan Badlishah, Jalan Langgar, Jalan Selamat, Jalan Petri, Jalan Pengkalan, Jalan Persekutuan

1.2 Objectives of Study

The main objectives of this research are:

(i) to identify factors which influence the level of service of crosswalks at signalized intersections.
(ii) to develop a regression model which can be used to determine the pedestrian level of service of crosswalks at signalized intersections.

2 FACTORS INFLUENCING PEDESTRIAN LEVEL OF SERVICE AT SIGNALIZED INTERSECTIONS

From preliminary observations and interviews held prior to data collection, several factors were considered in the development of the model. They can be grouped into three main categories as shown in Table 2.

Table 2. Factors considered in the P-LOS model development

Category	Factors
Pedestrian Factors	a. Pedestrian Flow b. Pedestrian Crossing Time c. Pedestrian Delay d. Pedestrian Sight Distance e. Pedestrian Waiting Time
Crosswalk Factors	a. Pedestrian Holding Area b. Crosswalk Width c. Crosswalk Surface Condition d. Crosswalk Marking
Roadway Factors	a. Number of Lanes b. Roadway Width c. Exclusive Left-Turn Lanes

However, initial regression analysis using all factors in Table 2 did not yield optimal results as most factors were found to be insignificant, or in other terms were not strongly related to P-LOS.

After several trials in which some factors were excluded from the analysis, a final model was developed and the selected factors were shown to have significance. The seven factors considered in the development of the P-LOS model are as follows:

(i) Pedestrian Flow
(ii) Pedestrian Crossing Time
(iii) Pedestrian Delay
(iv) Crosswalk Surface Condition
(v) Crosswalk Marking
(vi) Pedestrian Holding Area
(vii) Roadway Width

3 DEVELOPMENT OF THE P-LOS MODEL

The development of the P-LOS model involved (1) the collection of data, (2) a statistical analysis of the collected data using multiple linear regression, and (3) a model validation process using several statistical tests.

3.1 Data for the Dependent and Independent Variables

The P-LOS model consisted of a dependent variable and seven independent variables. The dependent variable was the P-LOS Score obtained through interviews and questionnaires. Pedestrians were asked to rate the crosswalks in terms of safety and comfort.

The independent variables were the factors as identified in section 2. Pedestrian flow (ped/hr), pedestrian crossing time (sec), pedestrian delay (sec), crosswalk surface condition (0 – poor, 1 – moderate, 2 – good), crosswalk marking (0 – not visible, 1 – slightly visible, 2 – highly visible), pedestrian holding area (m^2) and roadway width (m) were measured at the study locations. These data formed the input for the analysis. The data are shown in Appendix 1.

3.2 Data Analysis

The following are the assumptions made, prior to the development of the model using the multiple regression analysis method.

(1) For each value of the independent variables (X), there is an array of possible values for the dependent variables (Y) which is normally distributed about the regression line.
(2) The mean of the distribution of possible Y values is on the regression line, that is, the expected value of the error term is zero.
(3) The standard deviation of the distribution of the possible Y values is constant regardless of the X values.

(4) The error terms are statistically independent of each other, that is, there is no serial correlation.
(5) The error terms are statistically independent of X values.

From the analysis, the regression equation to determine the P-LOS Score took the form of:

$$\text{P - LOS Score} = 0.00023\left[CSC^4 + CM + PHA^4\right] + \frac{45.85499}{PCT^{1.5} + PD} + \frac{265.9332}{PF} + \frac{1}{RW}$$

where,

CSC = crosswalk surface condition (0 – poor, 1 – moderate, 2 – good)
CM = crosswalk marking (0 – not visible, 1 – slightly visible, 2 – highly visible)
PHA = pedestrian holding area (m^2)
PCT = pedestrian crossing time (sec)
PD = pedestrian delay (sec)
PF = pedestrian flow (ped/hr)
RW = roadway width (m)

To aid in the determination of the P-LOS of the crosswalk, a LOS table, as shown in Table 3, was developed as a basis for stratifying the model's numerical result into a level of service category.

Table 3. Level of Service Categories

Pedestrian Level of Service (P-LOS)	P-LOS Score
A	$8.5 < x \leq 10.0$
B	$7.0 < x \leq 8.5$
C	$6.0 < x \leq 7.0$
D	$5.0 < x \leq 6.0$
E	$4.0 < x \leq 5.0$
F	$x \leq 4.0$

3.3 Validation of the Model

Based on the summary output from the regression analysis, as shown in Appendix 2, a series of statistical tests were done to validate the model.

3.3.1 Coefficient of Determination (R-Square)

From the multiple regression analysis performed, the coefficient of determination or R-square value was 0.957 (refer to Appendix 2), which indicates that 95.7% of the variation in the predicted P-LOS Score has been explained by the explanatory variables, or in other words, the regression line. The R-square value obtained is exceptionally high and it indicates that the model is almost a perfect fit (an R-square value of 1 is a perfect fit).

3.3.2 T-Test

The T value, which is the square root of ratio between the Mean Square Regression (MSR) and the Mean Square Error or Residual (MSE), for this model is 12.083 or square root of F (=145.9994) in Appendix 2. With the significance level (α) and degree of freedom (d.f.) being 0.05 and 22 respectively, the critical-t value is 1.717. Since T is greater than critical-t, therefore it can be concluded that the relationship is significant and the model can be used to calculate the P-LOS Score.

3.3.3 t-statistic Test

From the summary output in Appendix 2, the value of t-statistic for every coefficient was compared to the critical-t value. Table 4 shows the significance test for the coefficients.

Table 4. Significance Test for the Coefficients

Coefficients	t- statistic	t-statistic > 1.717	Remarks
CSC, CM, PHA	2.384848	Yes	Significant
PCT, PD	2.469641	Yes	Significant
PF	5.358065	Yes	Significant
CW	3.208075	Yes	Significant

Since all values were larger than the critical-t value of 1.717, therefore all the coefficients are significant. Hence, they are accepted into the regression equation.

3.3.4 Outcome from the Validation Tests

Since the P-LOS model which was developed through this study has passed all three validation tests (as explained in sections 3.3.1 to 3.3.3), therefore it can be summed up that this model is valid and can be used to determine the P-LOS Score.

3.4 Comparison between Predicted and Observed P-LOS Scores

After successfully developing the P-LOS model, the P-LOS Score was predicted. The comparison between the predicted and observed P-LOS Scores is shown in Figure 1. The graph indicates that the P-LOS model which was developed through this study yielded results which are close to the observed values. Thus, it can be used to predict the P-LOS Scores.

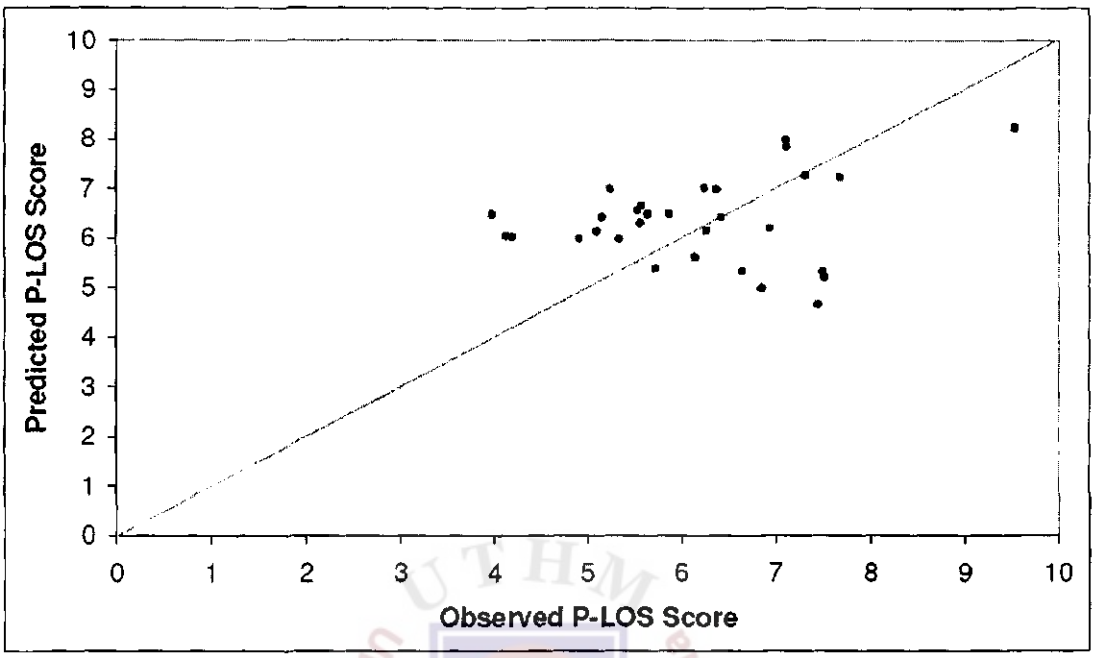

Figure 1. Observed versus Predicted P-LOS Scores

4 CONCLUSIONS AND RECOMMENDATIONS

From this study, it was found that the following factors influence the level of service of crosswalks at signalized intersections:

a) Pedestrian Flow
b) Pedestrian Crossing Time
c) Pedestrian Delay
d) Crosswalk Surface Condition
e) Crosswalk Marking
f) Pedestrian Holding Area
g) Roadway Width

This study also produced a P-LOS Model which can be used to determine the level of service of crosswalks at signalized intersections. The model is in the form of the following equation:

$$\text{P - LOS Score} = 0.00023\left[CSC^4 + CM + PHA^4\right] + \frac{45.85499}{PCT^{1.5} + PD} + \frac{265.9332}{PF} + \frac{1}{RW}$$

where,
CSC = crosswalk surface condition (0 – poor, 1 – moderate, 2 – good)
CM = crosswalk marking (0 – not visible, 1 – slightly visible, 2 – highly visible)
PHA = pedestrian holding area (m^2)
PCT = pedestrian crossing time (sec)
PD = pedestrian delay (sec)
PF = pedestrian flow (ped/hr)
RW = roadway width (m)

From the model, it can be recommended that in order to achieve high levels of service of crosswalks at signalized intersections, the following can be practiced in the planning and design of crosswalks at signalized intersections:

a) Shorten pedestrian crossing time by reducing crosswalk length and increasing crosswalk width.
b) Increase pedestrian flow by providing a longer pedestrian green time and providing larger walking space.
c) Reduce pedestrian delay by shortening cycle length of the traffic signal system.
d) Improve the condition of crosswalk surface through routine checks and maintenance.
e) Make sure that crosswalk markings at intersections are visible both day and night through routine checks and maintenance.
f) Provide adequate space for holding or accommodating pedestrians while waiting to cross.
g) Provide minimum required roadway width at the intersections in order to shorten crossing distance and time.

5 REFERENCES

Thambiah M. et al, 2005, Method to Determine Pedestrian Level-of-Service for Crosswalks at Urban Intersections, Eastern Asia Society for Transportation Studies, 2005, pp 127-136

Petritsch, T.A. et al., 2001, Pedestrian Level-of-Service Model for Signalized Intersections, Florida Department of Transportation (FDOT) Technical Report, 2001

Transportation Research Board, Highway Capacity Manual, 2000, National Research Council, Washington, D.C.,2000

Le Plante, J. and Kaeser, T., 2004, The Continuing Evolution of Pedestrian Walking Speed Assumptions, ITE Journal, Institute of Transportation Engineers. 74, no. 9., 2004, pp 32-40

Ryan, P., 2001, Reduced Waiting Times for Pedestrians at Traffic Signals, Policy Report Traffic and Transit, 2001

Mulder, K., 2003, Pedestrian Safety and Mobility Aids for Crossings at Bus Stops, Traffic Analysis Report. New Jersey, 2003

Jensen, S.U., 1999, Pedestrian Safety in Denmark, Transportation Research Record 1674, pp 61–69

Braun, R. and Roddin, M., 1978, Quantifying the Benefits of Separating Pedestrians and Vehicles, NCHRP Report 189 TRB, National Research Council, Washington, D.C., 1978

APPENDIX 1

Data for Dependent and Independent Variables

No	Name of Road	P-LOS SCORE	PCT	PF	PD	CSC	CM	PHA	RW
1	Jalan Kluang (Parit Raja)	6.04	8.01	110	60.5	1	0	4.09	10.3
2	Jalan Kluang (UTHM)	6.21	4.9	81	50.72	2	1	4.69	7.2
3	Jalan Omar	6.50	3.7	175	61.5	2	0	0	4.4
4	Jalan Mohd Khalid	6.50	7.18	123	40.36	1	1	0	11.5
5	Jalan Wawasan Utama	7.86	5.85	82	45.36	2	0	0	5.6
6	Jalan Rahmat	6.05	10.49	123	19.16	1	1	3.91	11.5
7	Jalan Ibrahim	6.57	8.93	82	8.42	1	1	0	12.3
8	Jalan Batu Pahat	5.35	6.7	53	72.08	1	1	0	10.8
9	Jalan Yahya	6.15	6.8	101	87.93	2	0	0	11.0
10	Jalan Arab	5.21	4.34	78	87.93	2	0	0	4.5
11	Jalan Bentayan	7.29	7.65	76	7.34	2	2	0	14.0
12	Jalan Abdullah	5.35	7.39	71	6.98	2	0	0	10.9
13	Jalan Salleh	7.00	4.7	85	80.65	2	0	0	6.7
14	Jalan Jorak	7.25	3.59	96	80.65	2	0	0	3.5
15	Jalan Jabbar	5.63	3.69	123	53.67	2	2	0	6.4
16	Jalan Temenggung Ahmad	5.40	5.92	78	53.67	1	2	0	7.4
17	Jalan Muar	6.32	4.94	76	85	1	0	0	7.6
18	Jalan Solok	7.03	4.8	102	85	2	0	6.29	6.5
19	Jalan Merlimau (Batu Gajah)	6.00	3.66	160	65.41	1	0	0	4.6
20	Jalan Merlimau (Melaka)	4.67	4.09	73	78.43	1	0	3	3.7
21	Jalan Johor	5.00	7.69	68	72.08	2	1	5.61	11.0
22	Jalan Bahru	6.67	5.81	121	62.71	2	1	0	7.3
23	Lebuhraya Darulaman	6.50	9.32	99	66.61	2	2	6.2	15.3
24	Jalan Mergong	6.44	8.1	100	45.05	2	2	7.1	10.4
25	Jalan Sultan Badlishah	6.00	8.01	333	0	2	2	5.32	12.2
26	Jalan Langgar	6.43	7.32	172	43.94	2	2	6.33	10.2
27	Jalan Selamat	8.25	5.35	211	0	2	2	8.32	5.7
28	Jalan Petri	7.00	5.49	102	89.23	1	0	6.96	7.3
29	Jalan Pengkalan	6.16	7.32	120	5.38	2	0	0	9.3
30	Jalan Persekutuan	8.01	6.64	73	39.5	2	0	4.32	7.4

PCT – Pedestrian Crossing Time (sec)
PF – Pedestrian Flow (ped/hr)
PD – Pedestrian Delay (sec)
CSC – Crosswalk Surface Condition (0,1,2)
CM – Crosswalk Marking (0,1,2)
PHA – Pedestrian Holding Area (m^2)
RW – Roadway Width (m)

APPENDIX 2

Summary Output of the Regression Analysis

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.978456
R Square	0.957377
Adjusted R Square	0.913997
Standard Error	1.423325
Observations	30

ANOVA

	df	*SS*	*MS*	*F*
Regression	4	1183.093	295.7734	145.9994
Residual	26	52.67218	2.025853	
Total	30	1235.766		

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
CSC, CM, PHA	0.00023	9.63E-05	2.384848	0.024666
PCT, PD	45.85499	18.56747	2.469641	0.020409
PFC	265.9332	49.63231	5.358065	1.31E-05
CW	12.03677	3.752024	3.208075	0.003531