

Assessing PLOS at Road Intersections using Fuzzy Set Theory

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Abstract: Pedestrian level of service (PLOS) is a measure of the quality of pedestrian facilities provided. Assessing the pedestrian level of service is very important for the improvement of pedestrian environment. This paper describes the results of study on the level of service provided and the importance of various parameters that affect the pedestrian level of service at road intersections. In the analysis, fuzzy set theory is applied and a composite pedestrian level-of-service index (PLOSI) is used to assess the level of service. The assessment at five intersections revealed that two intersections have PLOSI values less than the acceptance level. These two locations are lacking the pedestrian facilities and need to be improved. The method applied in this study may be useful in assessing the level of service at other intersections.

Key words: PLOS, Fuzzy Set, Intersections, Membership Functions, Defuzzification.

I. INTRODUCTION

Quality plays an important role in any service provided or to be provided and the effectiveness of the service is assessed on the basis of its quality. Due to resource crunch or improper planning, quite often the service quality is not given a priority. Better pedestrian facilities are essential for effective city transportation system. The pedestrian facilities should be designed according to pedestrian expectations so as to avoid hindrance to traffic. Thus providing expected PLOS and its assessment is a very important tool for the improvement of pedestrian environment at the intersections. Pedestrian expectations and perceptions vary in nature. Fuzzy set approach, generally regarded as an effective tool to process the qualitative information [1], is applied for rating of the PLOS factors, determining importance of factors, representing qualitative information through fuzzy-sets and to calculate PLOS. The fuzzy weighted average is based on algorithm developed by Dong and Wong [2]. The PLOS calculated using fuzzy set concept is compared with simple averaging method to know its applicability in identifying inadequacies in PLOS and its factors in different road intersections.

II. DATA COLLECTION

For the study, initially field work was carried out to know pedestrian movement and their needs. Five factors (Crossing Width/Lane width, Waiting Time, Waiting Area, Pedestrian Crossing Facilities and Pedestrian Volume) which are most correlated to the comfort and safety are considered for the study. The importance of the factors are estimated from expert opinion and user (pedestrian) perception survey. Total of 584 responses were obtained to determine the relative importance of the factors which affect pedestrian level of service.

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The importance (five levels) of factors at the road intersections were obtained from the pedestrians. Highest level being most important with letter A and lowest level as not important with letter E. Numerically these represent 5 and 1 respectively.

After getting importance, the next survey was conducted to get satisfaction rating of different PLOS factors. The pedestrians were requested to rate the existing quality of the facility they are using. The rating was again with five levels of linguistic descriptions. The highest rating is very good and lowest is the poor. On a scale of 1-5, 1 is poor operating condition of the particular factor and 5 represents very good operating condition of the factor.

III. PLOS BY SIMPLE AVERAGING

The composite pedestrian level of service-Index (PLOSI) for a road intersection is obtained combining all the factors responsible for contributing service level. It can be calculated as given below:

$$PLOSI = \frac{\sum_{i=1}^N Wi \times Si}{\sum_{i=1}^N Wi} \dots(1)$$

Here;

N - Total number of factors considered.

W_i - Importance of the i^{th} PLOS factor

S_i = Satisfaction level of the i^{th} PLOS factor

With respect to the intersection factor, the PLOSI can be calculated using the equation below:

$$PLOSI_i = S_i \times W_i \dots\dots (2)$$

If the importance of the PLOS factor is scaled in a way such that $\sum_{i=1}^N Wi = 1$ and the satisfaction level score is assigned on scale of unity, then for the highest service levels, highest value of PLOSI obtained will be 1. In worst condition the PLOSI value will be 0. All other values lie between 0 and 1. This can be interpreted that values closer to 1 are at higher service levels, whereas values closer to 0 represent very poor level of operating conditions. In real world facilities, generally highest level of service is desirable but often it is below ideal level. Same is applicable for the pedestrian facilities also. At any intersection, service level should be at least higher than average level. Many researchers have followed this principle [1,4,14], therefore minimum value of 0.6 has been considered as acceptance level of service for the present analysis. The analysis is also carried out using simple mathematical weighted averaging method for all the intersections. Expert as well as user (pedestrian) opinion regarding importance of PLOS factors in linguistic expressions are averaged to find weighted average values. Analysis of responses revealed that at the intersections, pedestrian crossing facilities have been given top priority (4.21, 0.255).

The calculations and results of five intersections are shown in **Table-1** as example. Taking minimum service level of the factors at 0.6, their adequacy or inadequacy from the minimum service level of 0.6 is indicated by negative or positive sign.

IV. PLOS BY FUZZY SET APPROACH

Many real world problems which involve uncertainty have been formulated mathematically by the researchers after the theory of fuzzy sets introduced by [15]. Juang and Amirkhanian [5] used this concept to develop pavement distress index. Fuzzy set theory is operated by way of membership functions which represent the extent to which an element belongs to a set. To evaluate PLOS, the importance and satisfaction rating of service quality for PLOS factor, is obtained as quality descriptors and recorded

by letter grades. Many researchers [3,5,6,9,16] have used fuzzy concept for ratings and weight calculations in the analysis of engineering problems which involve qualitative assessment. To compute PLOSI using fuzzy concept, four methodological steps proposed by Murugesan and Moorthy [7,8] have been adopted.

A. Factor Importance and Satisfaction Level

The importance or the weightage of the factors was determined from the responses obtained as very important to not important, with five levels represented from A to E and numerically equivalent to 5 to 1 respectively. Similarly for determining the satisfaction levels for the existing operating condition of the factors, responses were obtained from the pedestrians.

Table-1: Level of Service and their Deficiencies from Acceptance Levels

PLOS Factor	CW	WT	WA	PCF	PV	Overall PLOSI
Relative Weight (W_i) (Scale Value)	0.186	0.233	0.179	0.255	0.148	
Minimum Service Level (SL) (60% of Scale Value)	0.112	0.140	0.107	0.153	0.089	
Intersection- 1						
Satisfaction w.r.t. Unity (R_i)	0.253	0.600	0.860	0.787	0.480	
$PLOSI_i = W_i \times R_i$	0.047	0.140	0.154	0.201	0.071	0.613
adequacy or inadequacy from minimum service level, $PLOSI_i - (SL)$	-0.065	0.00	+0.047	+0.048	-0.018	+0.013
Intersection- 2						
Satisfaction w.r.t. Unity (R_i)	0.280	0.793	0.947	0.427	0.953	
$PLOSI_i = W_i \times R_i$	0.052	0.185	0.169	0.109	0.141	0.656
adequacy or inadequacy from minimum service level, $PLOSI_i - (SL)$	-0.060	+0.045	+0.062	-0.044	+0.052	+0.056
Intersection- 3						
Satisfaction w.r.t. Unity (R_i)	0.287	0.627	0.980	0.927	0.947	
$PLOSI_i = W_i \times R_i$	0.053	0.146	0.175	0.236	0.140	0.751
adequacy or inadequacy from minimum service level, $PLOSI_i - (SL)$	-0.059	+0.006	+0.068	+0.083	+0.051	+0.151
Intersection- 4						
Satisfaction w.r.t. Unity (R_i)	0.267	0.620	0.413	0.227	0.373	
$PLOSI_i = W_i \times R_i$	0.050	0.144	0.074	0.058	0.055	0.381
adequacy or inadequacy from minimum service level, $PLOSI_i - (SL)$	-0.062	+0.004	-0.033	-0.095	-0.034	-0.220
Intersection- 5						
Satisfaction w.r.t. Unity (R_i)	0.300	0.373	0.553	0.247	0.293	
$PLOSI_i = W_i \times R_i$	0.056	0.087	0.099	0.063	0.043	0.348
adequacy or inadequacy from minimum service level, $PLOSI_i - (SL)$	-0.055	-0.053	-0.008	-0.090	-0.046	-0.252

B. Fuzzy Membership Functions for Importance and Ratings

Every input value is assigned a relationship to a curve or space. This relationship is called membership function. This function defines degree of membership in terms of values between 0 and 1. Here the membership function is used to show an individual’s response which is subjective in nature and can be represented in a fuzzy space. The fuzzy sets representing the importance and their membership functions is shown in **Table-2** and fuzzy sets along with their membership functions is shown in **Table-3**. The degree of

membership for importance or satisfaction level can be found from the membership function assigned to each factor within specified interval. Separate membership functions are assigned for importance and satisfaction levels of the factors involved. In both the formulations, five levels of descriptions have been used to describe importance or satisfaction level of the PLOS factors. As reported in literature [2,5,6,11,12], the triangular membership function, because of its simplicity in application is used here to represent membership functions.



C. Evaluation of PLOS

The level of service provided to the pedestrians considering, operating conditions of PLOS factors is calculated by the equation.

$$R = \frac{\sum_{i=1}^N (R_i \times W_i)}{\sum W_i} \dots(3)$$

Where, R = Overall PLOS rating of a road segment/intersection;

R_i = the satisfaction level of the i^{th} PLOS factor

W_i = the importance of the i^{th} PLOS factor

N = Total factors in assessment.

Here the terms represented by letter grades are further represented with fuzzy sets which is represented by using a single number in simple numerical technique.

Substituting the values in the equation, the overall pedestrian level of service (PLOS) is calculated. The importance and satisfaction level ratings of PLOS factors as non-fuzzy inputs at three α - cut intervals for the road intersections are presented in **Table-4** and **Table-5** respectively.

Table-2: Membership Functions for Importance of Factors

Importance Level	Fuzzy Interval	Membership Functions (MF), Interval (0,1)	Triangular Fuzzy Numbers
Most Important	A	$f(y) = 5(x - 0.8), 0.8 \leq x \leq 1$	0.80, 1.00, 1.00
Important	B	$f(y) = 5(x - 0.6), 0.6 \leq x \leq 0.8$ $f(y) = 5(1 - x), 0.8 \leq x \leq 1$	0.60, 0.80, 1.00
Moderately Important	C	$f(y) = 5(x - 0.4), 0.4 \leq x \leq 0.6$ $f(y) = 5(0.8 - x), 0.6 \leq x \leq 0.8$	0.40, 0.60, 0.80
Slightly Important	D	$f(y) = 5(x - 0.2), 0.2 \leq x \leq 0.4$ $f(y) = 5(0.6 - x), 0.4 \leq x \leq 0.6$	0.20, 0.40, 0.60
Not Important	E	$f(y) = 5(x), 0.0 \leq x \leq 0.2$ $f(y) = 5(0.4 - x), 0.2 \leq x \leq 0.4$	0.00, 0.20, 0.40

Table-3: Membership Functions for Satisfaction Levels

Satisfaction Levels	Fuzzy Interval	Membership Functions (MF), Interval (0,1)	Triangular Fuzzy Numbers
Very Good	A	$f(y) = 5(x - 0.8), 0.8 \leq x \leq 1$	0.80, 1.00, 1.00
Good	B	$f(y) = 5(x - 0.6), 0.6 \leq x \leq 0.8$ $f(y) = 5(1 - x), 0.8 \leq x \leq 1$	0.60, 0.80, 1.00
Fair	C	$f(y) = 5(x - 0.4), 0.4 \leq x \leq 0.6$ $f(y) = 5(0.8 - x), 0.6 \leq x \leq 0.8$	0.40, 0.60, 0.80
Satisfactory	D	$f(y) = 5(x - 0.2), 0.2 \leq x \leq 0.4$ $f(y) = 5(0.6 - x), 0.4 \leq x \leq 0.6$	0.20, 0.40, 0.60
Poor	E	$f(y) = 10(0.3 - x)/3, 0.0 \leq x \leq 0.3$	0.00, 0.00, 0.30

D. Defuzzification and Result

The fuzzy quantities are converted into crisp quantities for further processing. For this conversion the method applied is regarded as defuzzification. This process ultimately calculates the overall pedestrian level of service (PLOS) which is a crisp number. Here α -cut method of defuzzification [5], is used. The α -cut concept for defuzzification and for calculating PLOSI is shown in **Figure-1**. From the figure, overall pedestrian level of service index can be calculated using the relation in equation (4):

$$PLOSI = (A_L - A_R + 1)/2 \dots(4)$$

Where PLOSI = Overall PLOSI

A_L : Area on the left side,

A_R : Area on the right side.

As per equation above and Figure-1, the PLOSI can assume values between 0 to 1 depending upon level of service being provided by the intersections. The value 1 or very near to it will give the indication of ideal or highest level of service and as the values deviate from 1, there is indication of lower level of service.



Table-4: Values at α - cut Interval for Importance

α - cut Interval	CW	WT	WA	PCF	PV
$\alpha = 0.0$	0.41, 0.81	0.57, 0.92	0.39, 0.79	0.64, 0.97	0.29, 0.69
$\alpha = 0.5$	0.51, 0.71	0.67, 0.85	0.49, 0.69	0.74, 0.90	0.39, 0.59
$\alpha = 1.0$	0.61, 0.61	0.77, 0.77	0.59, 0.59	0.84, 0.84	0.49, 0.49

Table-5: Values at α - cut Interval for Satisfaction Levels

Intersection	α - cut Interval	CW	WT	WA	PCF	PV
1	$\alpha = 0.0$	.05, .37	.40, .79	.66, .99	.59, .93	.28, .67
	$\alpha = 0.5$	.07, .23	.50, .69	.76, .92	.69, .86	.37, .56
	$\alpha = 1.0$	.09, .09	.59, .59	.86, .86	.79, .79	.45, .45
2	$\alpha = 0.0$	.08, .41	.59, .93	.75, .99	.23, .62	.75, 1.0
	$\alpha = 0.5$	.11, .28	.69, .86	.85, .97	.32, .51	.85, .98
	$\alpha = 1.0$	.15, .15	.79, .79	.95, .95	.41, .41	.95, .95
3	$\alpha = 0.0$	.09, .42	.43, .81	.78, 1.0	.73, 1.0	.75, .99
	$\alpha = 0.5$	.12, .29	.52, .71	.88, .99	.83, .96	.85, .97
	$\alpha = 1.0$	.16, .16	.61, .61	.98, .98	.93, .93	.95, .95
4	$\alpha = 0.0$	.07, .40	.42, .81	.21, .60	.03, .34	.17, .55
	$\alpha = 0.5$	.10, .26	.52, .72	.30, .49	.04, .20	.25, .43
	$\alpha = 1.0$	.13, .13	.62, .62	.39, .39	.05, .05	.32, .32
5	$\alpha = 0.0$	.10, .43	.17, .54	.35, .75	.05, .37	.09, .43
	$\alpha = 0.5$	.13, .30	.24, .42	.45, .65	.07, .23	.13, .30
	$\alpha = 1.0$	.17, .17	.31, .31	.55, .55	.09, .09	.17, .17

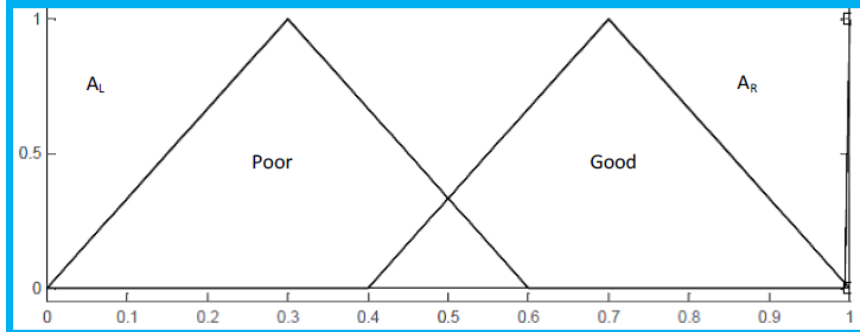


Figure-1: Parameters for calculating PLOSI

More the area on the left, the higher the level of service and vice versa. The final outputs, representing overall PLOSI of the road intersection after defuzzification, is shown in Table-6. Highest overall PLOSI value obtained is 0.736.

Table-6: Overall PLOSI (Fuzzy Set)

Inter-section	α -cut Intervals	Non Fuzzy Outputs for R	Overall PLOSI
1	$\alpha = 0.0$	0.419, 0.759	0.583
	$\alpha = 0.5$	0.499, 0.666	
	$\alpha = 1.0$	0.576, 0.576	
2	$\alpha = 0.0$	0.446, 0.780	0.736
	$\alpha = 0.5$	0.537, 0.705	
	$\alpha = 1.0$	0.627, 0.627	
3	$\alpha = 0.0$	0.553, 0.844	0.712

4	$\alpha = 0.5$	0.638, 0.783	0.330
	$\alpha = 1.0$	0.725, 0.725	
5	$\alpha = 0.0$	0.182, 0.539	0.287
	$\alpha = 0.5$	0.241, 0.419	
	$\alpha = 1.0$	0.299, 0.299	

V. CONCLUSION

The final results (PLOSI) from two approaches are shown in **Table-7**. The PLOSI calculated by the two approaches show similar trends. The values obtained by fuzzy set approach are slightly lower than that of numerical rating approach but the difference is not much. This variation is due to membership function value of weights starting from zero while actual weightage starts from one. As we shift the starting membership value towards one from the zero, the results of two approaches will come closer. This shows that for symmetrical membership functions, the results from two approaches are generally same. However for unsymmetrical membership functions, fuzzy set approach will produce better results as it takes into consideration uncertainty. The highest level of service is found at intersection 3 while lowest at intersection 5. The locations were physically verified by the author and the results obtained by the study match with the existing operating conditions of the factors at these locations. The fuzzy set approach is recommended for assessing pedestrian level of service at other intersections also.

Table-7: PLOSI Results

Inter-section	Overall PLOSI		Difference
	Numerical Rating Approach	Fuzzy Set Approach	
1	0.613	0.583	0.030
2	0.656	0.620	0.036
3	0.751	0.712	0.039
4	0.381	0.330	0.051
5	0.348	0.287	0.061

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