Application of Fuzzy Logic to the Optimal Location of Public Utilities: A Case Study of Pedestrian Bridges

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Abstract. The level of utilization of many public utilities is, most often, influenced by their locations. Huge public funds are spent annually on the provision of several public infrastructures, such as pedestrian bridges, that are grossly underutilized due to their poor location or citing. This study was aimed at developing a fuzzy logic based decision support system for the optimal location of pedestrian bridges in a typical Nigerian city. Various factors, and their interactions, that affect utilization of any pedestrian bridge were identified and characterized. Utilization data on twenty eight existing pedestrian bridges, spread across two states in Nigeria were obtained and analyzed. The triangle and trapezoidal membership function were used to build a fuzzy inference system modeling the dynamics of utilization. The model was tested with the real life data. Four factors: traffic speed, vehicle traffic volume, proximity to market and proximity to bus stop, among other factors, were prominent in influencing utilization level. The model achieves more than 75% accuracy in deciding the suitability of a location based on level of utilization. It is concluded that the fuzzy logic approach is a veritable decision support tool for public facilities location decision problem.

Keyword: Facility Location, Fuzzy logic, Membership Function, Pedestrian Bridge

1. Introduction

The utilization or otherwise of many public utilities is, most often, the function their location. Huge public funds are spent annually in the provision of several public infrastructures, such as pedestrian bridges, that have turned out be waste because they are unutilized or grossly underutilized due to poor location citing. This wasteful phenomenon can be remediated if effective decision support systems for determining optimal locations are available to decision makers at design stage of these facilities. Hence this study was aimed at developing a fuzzy logic based decision support system for the optimal location of public utilities, using the pedestrian bridges in a typical Nigerian city as case study. Specifically the objectives of the study are: a) To study and identify the relevant variables in the pedestrian bridge systems that affect their utilization, b) To build a fuzzy inference engine model of this system, and c) To test and validate this model using real life data on existing bridges in some selected locations in Nigeria.

In urban areas pedestrian bridges are usually provided to make crossing of highways safe for pedestrians. Ironically several pedestrians are knocked down, killed or injured, by moving vehicles, not too far from these facilities that they have ignored because the users do not find the location 'convenient'. In fact the need for the optimal of location of public utilities is best illustrated by several sights of unutilized pedestrian bridges on the highways. However the complexities of the associated location problem make it virtually impossible for such decisions to be based purely on planners' intuitions and experience; there is the need for some decisions support systems. Meanwhile traditional optimization approaches based on crisp mathematical models are inadequate for such decision problems which are characterized by set of factors which are mostly vague or fuzzy in descriptions and dominated by imprecise or uncertain data [1, 2, 3]. Hence our attempt at applying the fuzzy logic approaches to this problem.

1.1. The Fuzzy Set Theory and Fuzzy Inference System

Fuzzy set theory provides a mathematical tool for modeling uncertain, imprecise and vague data encountered in most real life situations. Fuzzy set theory is able to cope with the imprecision and uncertainty which is inherent in human judgments and decision making processes by the use of linguistic terms or variables and degrees of membership. A Linguistic Variable, the equivalent of mathematical variable, can take words or sentences as values. For instance, a linguistic variable X with label Speed, can assume values like 'Very fast', 'Fast', 'Slow', or 'Very slow'. Fuzzy set can classify elements into a continuous set using the concept of membership functions (MF) and degree of membership (μ) to represent the gradual changes from 0 to 1. So in fuzzy logic, the truth of any statement becomes a matter of degree [3, 4, 5]. Some widely used MFs are Gaussian, Generalized bell shaped, Gaussian curves, Polynomial curves, Trapezoidal, Triangular and Sigmoid MFs. The trapezoidal, triangular MFs which are the most widely used in literature have been adopted for this study from the point of view of simplicity, convenience, and speed [6, 7].

The fuzzy expert system technique, one of the successful fuzzy logic applications for solving real-world problems, is based on fuzzy inference composed of membership functions, fuzzy logic operators, and if-then rules as elements. Fuzzy inference is really the process of formulating the mapping from a given input to an output using fuzzy logic to provide a basis from which decisions can be made, or patterns discerned. Two commonly used fuzzy inference systems are the Mamdani-type and Sugeno-type [8, 9]. The Mamdani Fuzzy Inference System [3] was used for our model.

2. Mode Development

2.1. Data Collection and Study Location

Data for model development and parameterization were obtained from observation of activities around 28 pedestrian bridges located in Lagos and Ibadan, two of Nigeria largest cities, with the highest concentration of Pedestrian Bridges, from pedestrians, ministry of works and transport officials and other experts through interviews and questionnaire administrations.

2.2. Linguistic Variables and Term Sets

The utilization level (Output Factor) of a given bridge was measured by the level of Human Traffic Flow (HTF) across the Pedestrian Bridge (PB). Through search of the literature, observations and discussion with road users, a number of environmental, and urban behavioural factors as well as road characteristics that influence HTF were identified as Input Factors. The critical input factors are Average Vehicular Speed around PBs, Average Traffic Volume, Proximity to Market, and Proximity to Bus stop. Appropriate linguistic variables, with their term sets, were defined for the factors as summarised in Table1.

TABLE1: Linguistic Variables description

Linguistic Variables	Term sets (Abbreviation)	Linguistic Variables	Term sets (Abbreviation)
	Stage 1 Input		
Traffic Speed	Very Slow (VS)	**Vehicular Traffic Volume**	Very Low (VL)
	Slow (S)		Low (L)
	Fast (F)		High (H)
	Very Fast (VF)		Very High (VH)
	Stage 1 Output/stage 3 Input		
Vehicular Flow	Very poor Flow (VPF)		
	Poor Flow (PF)		
	Average Flow (AF)		
	High Flow (HF)		
	Stage 2 Input		
Proximity to Market	Within Market (WM)	**Proximity to Bus stop**	At Bus stop (ABS)
	Distant market (DM)		Near Bus stop (NBS)
	No Market		Far from Bus stop (FBS)
	Stage 2 output/stage 3 Input		
Pedestrian Flow	Low flow (LF)		
	Average flow (AF)		
	High Flow (HF)		
	Stage 3 Output		
Location suitability	Less preferred (LP)		
	Averagely Preferred (AP)		
	Highly Preferred (HP)		
	Extremely Preferred (EX)		

2.3. Model Description

The resulting model, a three stage fuzzy inference system, is summarized in Fig 2. Crisp input variables were transformed into fuzzy variables (fuzzification) at stages 1 and 2. These variables were subjected to the fuzzy inference engine to obtain the fuzzy input variables for stage 3. The fuzzy linguistic variable output from stage 3 FIS was then defuzzified to obtain a location criteria index.

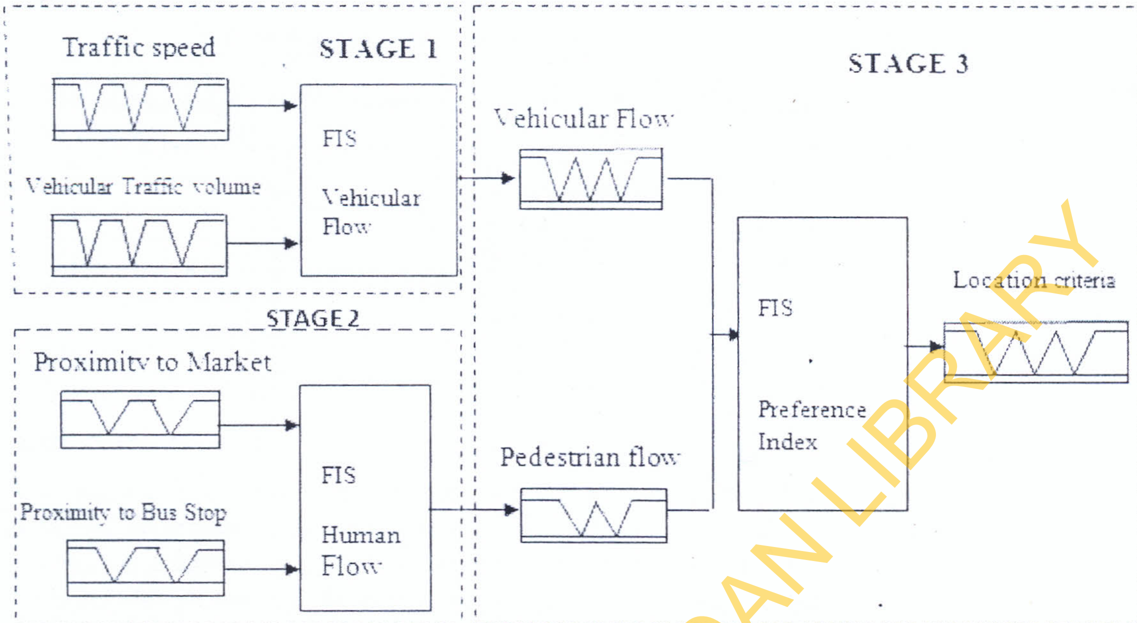

Fig. 1. The Fuzzy Logic Model

2.4. Membership Functions

The trapezoidal and the triangular membership functions were adopted in defining the degree of membership (μ) in the associated Fuzzifier/ Defuzzifier. Figs 2,3 and 4 with term sets defined by either the trapezoidal or triangular membership functions are sample fuzzifier interfaces [10].

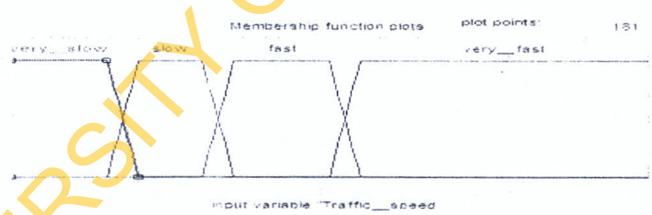

Fig. 2: Trapezoidal Membership Function for Traffic speed fuzification

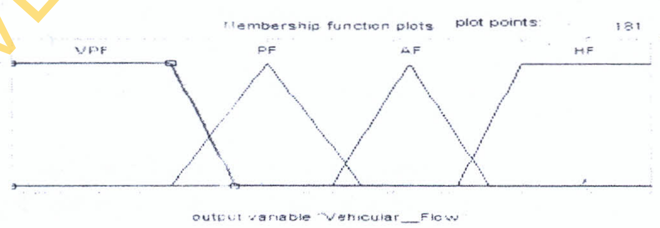

Fig. 3 Trapezoidal and triangular Membership Functions for Vehicular Flow fuzification

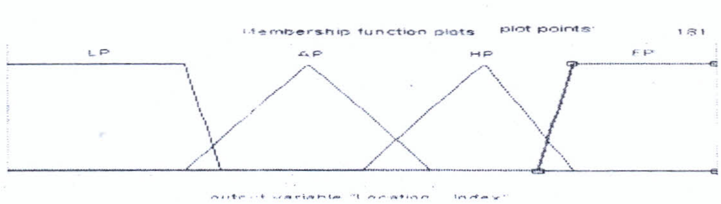

Fig. 4 Trapezoidal and triangular Membership Functions location criteria defuzification

3. Model Application and Results

The proposed model was applied in eight different PB locations where the actual percentage utilization (no of pedestrians that used a PB a road divided by total number of pedestrian that crossed the road within a time band) was obtained. These were compared with the corresponding values predicted by the fuzzy model as summarized in table 2.

TABLE 2: Comparison of Predicted Utilization and actually Utilization

Pedestrian bridge Location	% Utilization	Actual Users' Preference based on % Utilization	Predicted Users' Preference Fuzzy logic	Remark
A	12.0	Less preferred	Less preferred	Valid
B	89.0	Extremely preferred	Extremely preferred	Valid
C	0	Less preferred	Less preferred	Valid
D	89	Extremely preferred	Averagely preferred	Invalid
E	75	Highly preferred	Highly preferred	Valid
F	82	Extremely preferred	Extremely preferred	Valid
G	68	Highly preferred	Highly preferred	Valid
H	60	Averagely preferred	Highly preferred	Invalid

4. Conclusion

Four factors: traffic speed, vehicle traffic volume, proximity to market and proximity to bus stop, among other factors, were prominent in influencing utilization level. The model achieves more than 75% accuracy in deciding the suitability of a location based on utilization. It is concluded that the fuzzy logic approach is a veritable decision support tool for public facilities location decision problem.

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