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DEVELOPMENT OF A FUZZY EXPERT SYSTEM TO PRIORITIZE TRAFFIC CALMING PROJECTS

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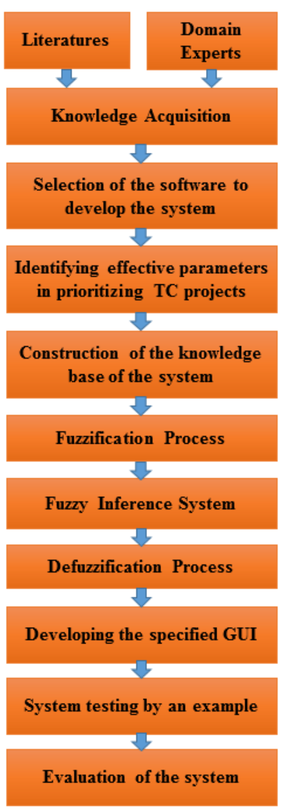
Graphical abstract



Abstract

Nowadays, due to the constraints of budget and time, the prioritization of traffic calming projects before installation of traffic calming measures is vital for transportation engineers and urban planners. The purpose of this study is to develop an expert system for prioritizing streets that are affected by problems associated with traffic safety using Fuzzy Logic. Expert systems have been used widely and globally for facilitating decision-making processes in various fields of engineering. Due to the uncertainty and vagueness in traffic and transportation related problems, the use of fuzzy logic in the inference engines and decision-making processes of expert systems, is effective. In the proposed expert system, effective parameters in prioritizing traffic calming projects in residential streets including traffic volume, residential density, differential speed and number of accidents are investigated. The Fuzzy Logic toolbox, which is embedded in MATLAB (R2010b), is employed to design and simulate this expert system on the basis of Fuzzy Logic. A specific GUI was developed for this purpose. By developing this system, engineers and decision-makers will be able to rank projects according to their importance. This expert system was tested through prioritizing a number of residential streets in the city of Tehran. The output of the tests showed that the proposed system is helpful in prioritizing different traffic calming projects. Finally, the evaluation of the system was conducted. According to the assessment, most evaluators acknowledged the efficiency and effectiveness of the system.

Keywords: Fuzzy logic, expert system, rules, traffic calming projects, prioritizing

1.0 INTRODUCTION

Traffic calming is a set of engineering measures and management techniques employed to reduce traffic speed and cut-through traffic in residential areas [1]. Applying traffic calming strategies can enhance the safety of non-motorized transportation users and residents of local neighborhoods [2]. Different traffic calming strategies include vertical deflections, horizontal deflections, narrowing measures and volume control measures [3]. Increasingly alarming traffic safety issues, such as speeding and cut-through traffic, have led engineers and urban planners to implement traffic calming strategies. Before proceeding with the implementation of measures, creating a system to identify projects with higher priorities is essential. Employing traffic calming strategies in all residential streets is not cost effective or may not be necessary. Furthermore, restriction in the allocation of funds is a major concern for decision-makers. Hence, finding a methodology and a framework to prioritize the alternatives is an extensive task [4]. Evaluation of traffic calming projects needs specific knowledge and experience; which novice engineers and civil engineers might not be familiar with. Developing an expert system to prioritize traffic calming projects can help young engineers to deal with the identification of projects that require immediate action. Expert systems are computer-based applications designed to mimic the human reasoning process [5]. An expert system for prioritizing traffic calming projects can be built on knowledge obtained from domain experts and relevant literatures. The output of the system is the overall rating for each alternative that enables users to compare the alternatives.

In this study, Section 2 discusses the history of prioritizing traffic calming schemes. The importance of using expert system applications and the combination of an expert system with a fuzzy logic method will be elaborated in Section 3. Section 4 will then describe the development process of the proposed system. In Section 5, an example of using this system, to prioritize a number of residential streets, is presented. Evaluation of the expert system by its users and domain experts is carried out in Section 6. As a conclusion, Section 7 will produce the discussion-conclusion of the study.

2.0 HISTORY OF PRIORITIZING PROJECTS

There are different methods for prioritizing traffic calming projects in residential areas. Due to the significance of prioritization in traffic calming projects, this subject is included in most traffic calming manuals and standards [6]. Generally, traffic calming manuals are provided for a specific city or area based on the efforts of local decision-makers; according to their judgment. Therefore, the range of points and the way effective parameters are used may vary from one place to another. Portland (USA) and Canberra (Australia) are two cities that have great experience in traffic calming studies and prioritization of traffic calming projects.

In Portland's prioritizing scheme, the total number of points that can be allocated for each project is 100. Effective parameters, such as pedestrian facilities, pedestrian trip generators (only collector streets), residential density, traffic volume, public transit (only collector streets) and traffic speed are included in the Portland scheme [7]. In Canberra's pointing scheme, 85th percentile speed, daily traffic volume, peak hour traffic, percentage of heavy vehicles, through traffic, number of accidents in the past five years, traffic noise and the existence of trip generators (only collectors) are selected as effective parameters for prioritizing traffic calming projects [8].

AHP technique is an innovative method to facilitate decision making process. This method can be used in engineering tasks as well as traffic calming prioritization process. In this method, appropriate criteria must be selected to compare alternatives [9]. In a research study, for prioritizing traffic calming projects, six criteria including emergency vehicle access, public transit access (only collectors), pedestrian facilities, traffic volume, trip generators (only collectors) and vehicle speed were selected for comparing alternatives which represented desired streets. In this study, three streets in two cities (Salt Lake City and Portland) were selected to be prioritized. A team of engineers was asked to perform pairwise comparison judgment in an attempt to determine the weight of each criterion. Data related to different traffic calming projects was collected from the U.S. department of transportation and submitted to the engineers. Furthermore, local residents and property owners along the selected streets were invited to express their opinions about the condition of the streets (with reference to the criteria) to the engineers by using interviews and questionnaires (local TV stations and newspapers enhanced these activities). Normalized scores obtained from the judgment revealed that traffic speed was ranked the highest, followed by pedestrian facilities, emergency access, trip generators and traffic volume [8].

3.0 EXPERT SYSTEM AND FUZZY LOGIC

An expert system as a computer application is an Artificial Intelligence (AI) program. The role of an expert system is to emulate the decision-making processes of human experts [10]. The main difference between expert systems and conventional computer programs is their ability to deal with problems by reasoning [5]. This ability makes expert systems popular among engineers and decision-makers. Expert systems are applied in various fields, such as science, medical and engineering [11]. Furthermore, expert systems can be employed to provide recommendations to users in different sectors [12]. Creating and developing within a computer system enables the expert system to store a large amount of knowledge in the form of computer language and logical rules [13]. Converting knowledge into the form of rules enables an expert system to uncover solutions that would otherwise not be possible; because there is lack of readily available help by experts [14].

Fuzzy logic is a problem solving method, which is referred to as a theory of vagueness; because rather than a fixed true and false concept in traditional logic reasoning, it deals with truth values that range between 0 and 1. In traditional and classical logic reasoning, the answer is defined in true or false statements and the concept of conclusion is black or white. Fuzzy logic decision-making is not only 0 and 1, but also contains values between 0 and 1 to simulate the mechanism of the human brain in the process of thinking and reasoning. Fuzzy logic can use linguistic variables to facilitate the presentation of facts and rules in fuzzy logic theory. Linguistic variables can be defined in fuzzy logic theory as low, medium, high, and very high. Temperature is the best example of fuzzy logic theory; where the linguistic variables, which include cold, cool, nominal, warm and hot, are defined between 0 and 100 degree Celsius. [15], [16].

A fuzzy expert system employs fuzzy logic over Boolean logic. Fuzzy expert systems are a combination of input/output membership functions and rules that are used to match facts and data against rules. A fuzzy expert system generally uses IF-THEN rules for its reasoning and judgment process. Due to the presence of uncertainty and imprecision in most of engineering fields, fuzzy logic is a useful method for developing an expert system [17].

4.0 DEVELOPMENT OF PRIORIA

A fuzzy expert system uses a fuzzy logic method to produce solutions. In this research, the output of the proposed system is derived from the fuzzy inference engine and fuzzy rule base. The main purpose of this system is to prioritize traffic calming projects using fuzzy logic reasoning. This fuzzy system will help engineers to select projects with a higher priority. In this section, the methodology for developing a fuzzy expert system to prioritize traffic calming projects is presented. Figure 1 illustrates the framework of this study.

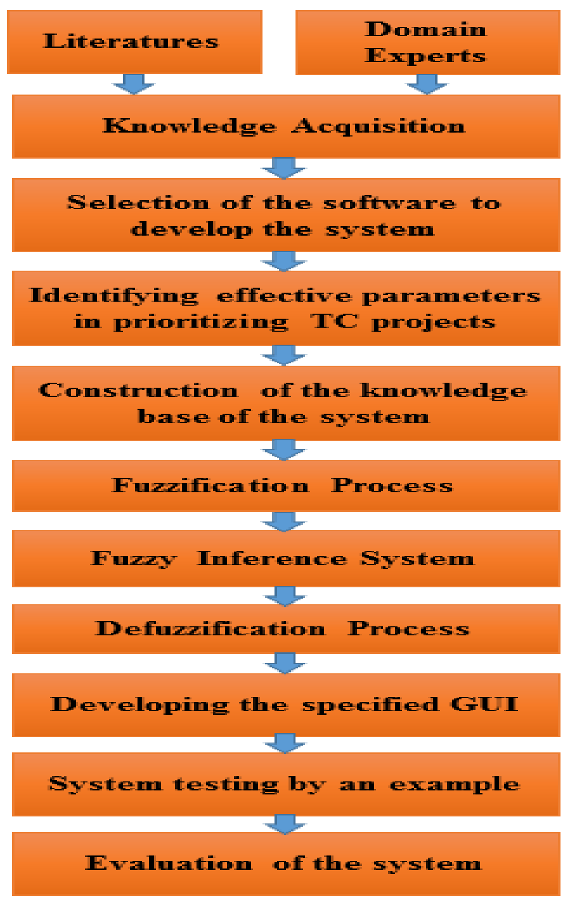


Figure 1 Framework of the study

4.1 Knowledge Acquisition

Literary works in the field of traffic calming and interviews conducted with domain experts were employed to develop the knowledge base of the expert system. Traffic calming manuals and traffic safety reports were used to compose the knowledge foundation. In the literary works, for example (as mentioned in Section 2), effective parameters in prioritizing traffic calming projects were introduced. Table 1 represents a list of relevant written sources for the knowledge acquisition process.

Interviews with domain experts are essential to construct an expert system. In this study, 10 traffic safety experts, with more than 10 years' experience, were selected for interview sessions. These experts have researched and worked in traffic calming studies and have useful information for dealing with traffic safety problems. These experts were asked to identify effective parameters, develop rules, and provide opinions regarding the output of the system.

Table 1 List of relevant sources employed in the knowledge acquisition

No.	Title	Year	Publisher
1	Traffic Calming: State of the Practice [1]	1999	FHEA
2	Alaska Traffic Calming Manual [3]	2001	DOWL
3	Pennsylvania Traffic Calming Manual [18]	2001	PDOT
4	Tehran Traffic Calming Manual [19]	2010	TTTO
5	Traffic Calming Benefits & Costs [20]	1999	VTP
6	Speed Management [21]	2006	OECD
7	Speed Management (A road safety manual for decision-makers and practitioners) [22]	2008	WHO
8	Traffic Calming Schemes [23]	2003	SWOV
9	A Policy on Geometric Design of Highways & Streets [24]	2011	AASHTO
10	The Manual for Streets [25]	2007	TRL

4.2 Selection of Building Tool

In this research, MATLAB (R2010b) fuzzy logic toolbox was used as a building tool of the proposed system. This toolbox provides facilities for users and decision-makers to design and run an expert system based on fuzzy logic theory. A fuzzy logic toolbox has a powerful environment; in which developers can generate fuzzy rules and modify them easily. This toolbox gives fuzzy logic an added advantage, as it is a useful tool to construct intelligent systems. The ability to deal with a large number of rules and introduce different methods to handle problems is the two main advantages of this toolbox.

4.3 Effective Parameters and Membership Functions

Interviewing domain experts and referring to the literatures assisted the knowledge engineer to identify effective parameters in prioritizing traffic calming projects. Daily traffic volume, differential speed (the difference between the posted speed limit and operating speed), residential density and the number of accidents, were chosen as input parameters. In the present study, we assumed that basic infrastructure of streets, including street lighting, road signs, road markings, sidewalks and pedestrian ramps were provided for road-users.

In follow-up research, daily traffic volume was measured by the number of vehicles passing through a study street per day. Differential speed was measured by kilometres per hour. Residential density was measured by the number of dwelling units per hectare and the number of accidents was measured by EPDO (Equivalent Property Damage Only) per 100-metre road section. For calculating EPDO, Equation 1 was employed as follows:

$$EPDO = (1 \times number\ of\ PDC) + (5 \times number\ of\ IC) + (10 \times FC)$$

(Eq.1)

Where:

PDC= property damage crashes, IC= Injury crashes, FC= fatal crashes

The output parameter is the overall rating that demonstrates the score that each traffic calming project earns after fuzzy computing. This means that streets with higher scores have higher priorities; in terms of implementing traffic calming measures. In this study, triangular and trapezoidal shaped graphs were used for developing the membership functions of input and output of the fuzzy system. Membership functions of input and output variables are represented in Figure 2. Linguistic terms, including "low," "medium" and "high" were used to denote membership functions of the input variables. Linguistic terms, including "very low," "low," "medium," "high" and "very high" were used to demonstrate membership functions of the output variable. These membership functions were developed to transform crisp values into fuzzy values.

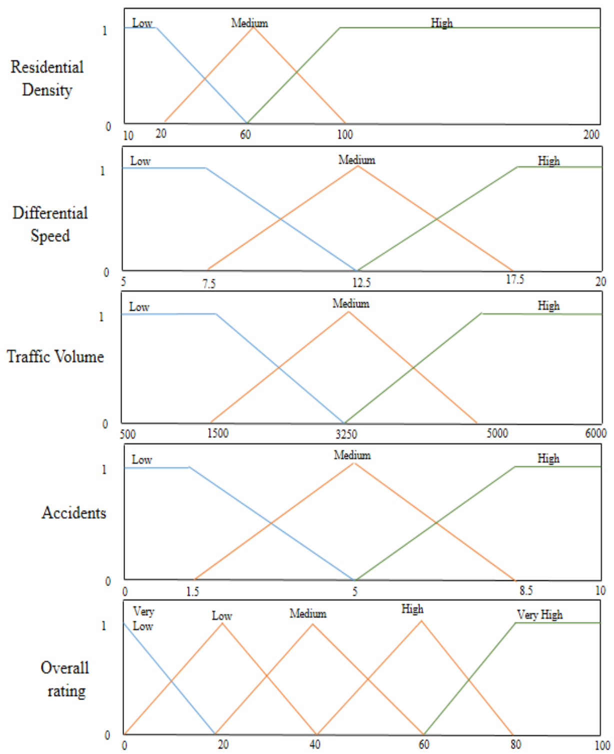


Figure 2 Membership functions of input and output variables

For example, the residential density parameter was divided into three membership functions. Low residential density includes areas with between 10 and 60 dwelling units per hectare (areas with single family buildings were included in this category). Medium residential density covers areas with a maximum number of 100 dwelling units per hectare and a minimum number of 20 dwelling units per hectare. The number of building stories varied from 2 to 3 stories. High residential density includes areas with between 60 and 200 dwelling units per hectare (areas with 4 story buildings or more and residential condominiums are included in this category).

4.4 Construction of Fuzzy Rules

The knowledge base of the proposed system consists of a number of fuzzy rules. Rules are regarded as the most common tools for representing knowledge in the development of an expert system. A forward chaining process is suitable for expert system, based on production rules [26]. The fuzzy rules employed in this system are represented in the form of 'IF' (condition statement) and 'THEN' (action statement) sentences. The overall rating point of each traffic calming project, which represents the output of the system, is dependent on the structure of the rule base. Combined rules, which consisted of four conditional statements connected with 'AND', were used.

Before constructing the fuzzy rules, in order to make a proper judgment about the significance of input variables, an AHP technique was employed to estimate the normalized weights of the variables, including differential speed, number of accidents, traffic volume and residential density. AHP is a branch of the MCDM (Multi Criteria Decision-Making) tool, developed to assist decision-makers choose the appropriate alternative among different options [27]. Impact on road safety and impact on NMT (Non-Motorized Transportation) were chosen as criteria and the mentioned variables were considered as the alternatives. Figure 3 shows the hierarchical structure of the proposed AHP model. Expert Choice software was employed to develop and analyse the AHP model. Four domain experts participated in this section. Through a series of judgments, including pairwise comparisons of criteria against the goals and pairwise comparison of alternatives against the criteria; normalized weights of the alternatives were calculated. Based on the results, the number of accidents and differential speeds, which had almost identical normalized weights, was considered more important than the other two criteria. The weight of traffic volume was higher than the residential density.

After estimating the significance of the variables, construction of the fuzzy rules was launched. As a result of the combination of membership functions associated with the input and output of the system (as mentioned in Section 4.3), the number of (3*3*3*3=) 81 fuzzy rules was produced. Table 2 shows examples of the fuzzy rules utilized in this study.

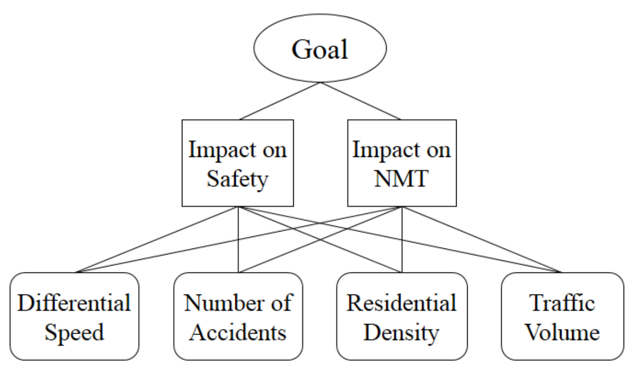


Figure 3 Hierarchical structure of the proposed AHP model

Table 2 Examples of Fuzzy Rules

Rules No.	Rule Structure
1	IF (Res_density is low) AND (Diff_speed is low) AND (Traf_Vol is low) AND (Accident is low) THEN (Rating_point is very low)
2	IF (Res_density is medium) AND (Diff_speed is low) AND (Traf_Vol is low) AND (Accident is low) THEN (Rating_point is very low)
3	IF (Res_density is high) AND (Diff_speed is low) AND (Traf_Vol is low) AND (Accident is low) THEN (Rating_point is low)
4	IF (Res_density is high) AND (Diff_speed is low) AND (Traf_Vol is low) AND (Accident is low) THEN (Rating_point is low)
5	IF (Res_density is high) AND (Diff_speed is low) AND (Traf_Vol is low) AND (Accident is low) THEN (Rating_point is low)
6	IF (Res_density is medium) AND (Diff_speed is low) AND (Traf_Vol is medium) AND (Accident is low) THEN (Rating_point is low)
7	IF (Res_density is high) AND (Diff_speed is high) AND (Traf_Vol is high) AND (Accident is low) THEN (Rating_point is high)
8	IF (Res_density is high) AND (Diff_speed is high) AND (Traf_Vol is high) AND (Accident is low) THEN (Rating_point is high)
9	IF (Res_density is high) AND (Diff_speed is high) AND (Traf_Vol is high) AND (Accident is high) THEN (Rating_point is very high)
10	IF (Res_density is high) AND (Diff_speed is high) AND (Traf_Vol is low) AND (Accident is high) THEN (Rating_point is very high)

4.5 The Process of Fuzzification

Fuzzification is the process of converting crisp input values to the degrees of fuzzy membership functions. Fuzzy values of a crisp input can be determined by intersecting the input value to the membership functions associated with each input variables. For example as shown in Figure 4, the speed differential of 9 km/h results in a degree of 0.3 of "medium" membership function and a degree of 0.7 of "low" membership function.

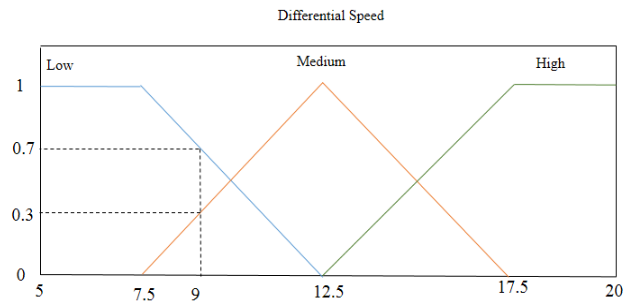


Figure 4 Degree of membership functions

4.6 Inference Engine

Different types of fuzzy inference engines can be used to develop a fuzzy expert system; however, Mamdani and Sugeno are the two most significant [28]. The Mamdani fuzzy inference method was employed to match rule-bases and input facts. The Mamdani method is commonly used to formulate engineering problems. In this regard, max-min methods were used. The min operator was employed to perform the 'AND' function and the max operator was employed to perform the 'OR' function. Aggregation of fuzzy sets was carried out using the max method. After the aggregation was finalized, the system was ready for the defuzzification process.

Figure 5 shows the structure of a fuzzy inference system. The illustration shown in Figure 6 shows an example of the 'AND' method and aggregation of fuzzy rules in the proposed expert system when in a study street, residential density is 60 DU/Hec, differential speed is 7.5 km/h, traffic volume is 1500 veh/day and accident (EPDO) is 7.5.

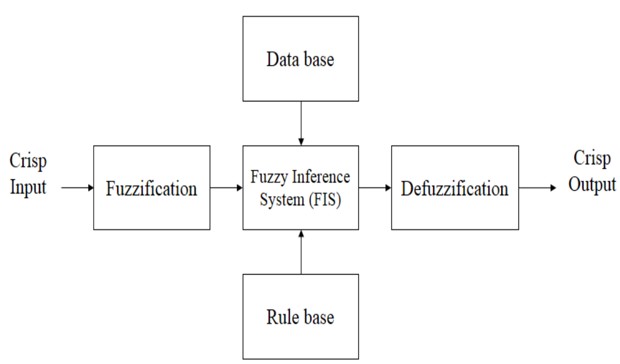


Figure 5 The process of a fuzzy inference engine system

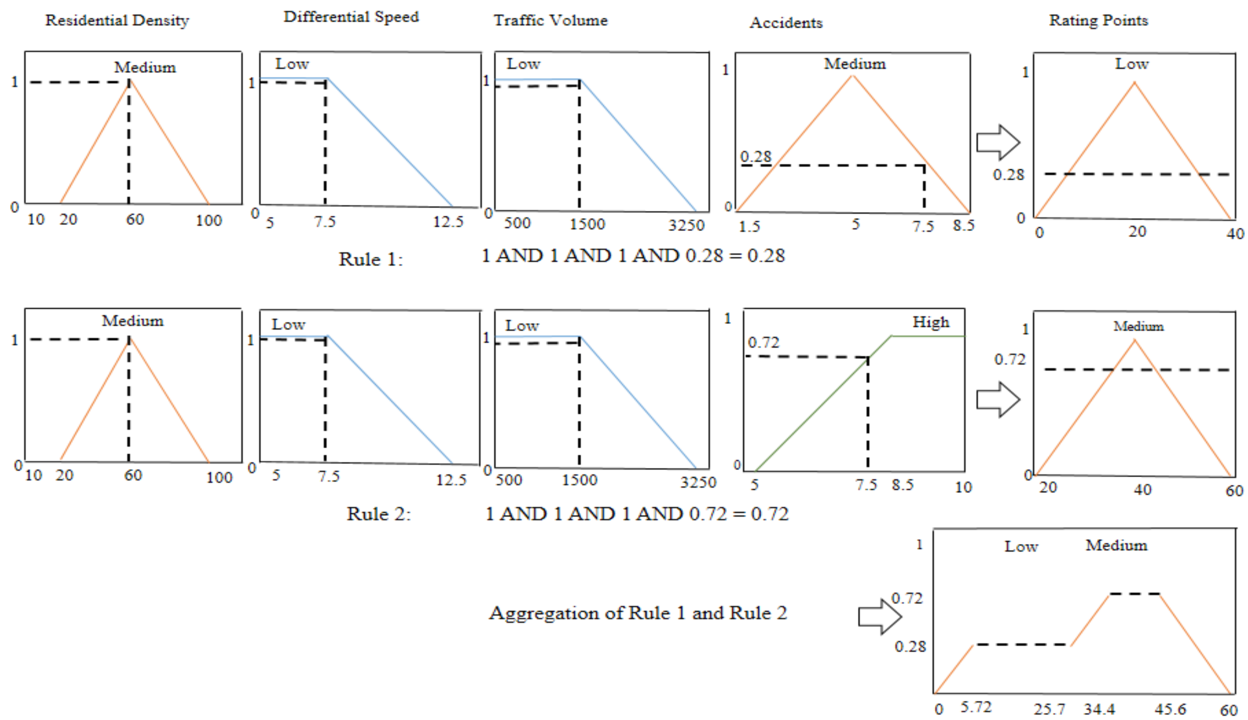


Figure 6 An example of AND method and aggregation of fuzzy rules

4.7 Defuzzifier

Different methods can be used for the defuzzification process, such as centroid method centre of sums, centre of largest area, weighted average methods and first of maxima [29]. In this research, centroid method or the centre of gravity approach (a useful and common method for defuzzification), was used to transform the aggregated fuzzy values of the system output into a single crisp value (as demonstrated in Equation 2 below):

$$Z = \frac{\int_a^b \mu_A(x)xdx}{\int_a^b \mu_A(x)dx} \qquad \text{(Eq. 2)}$$

Where:

Z= crisp value, μ_A = membership value, a and b represent the intervals

For example, the defuzzification process of the previous example was carried out as below. The crisp value of the process was 33.55.

$$Z=[\int_0^{5.72}(0.05x)xdx + \int_{5.7}^{25.72}(0.286)xdx + \int_{25.7}^{34.4}(0.05x - 1)xdx + \int_{34.4}^{45.6}(0.72)xdx + \int_{45.6}^{60}(-0.05x + 3)xdx] \div [\int_0^{5.72}(0.05x)dx + \int_{5.7}^{25.7}(0.286)dx + \int_{25.7}^{34.4}(0.05x - 1)dx + \int_{34.4}^{45.6}(0.72)dx + \int_{45.6}^{60}(-0.05x + 3)dx]=33.55$$

4.8 User Interface

A user interface is a medium between end-users and an expert system for gathering recommendations to solve problems [30]. The Prioria user interface is a customized interface of MATLAB fuzzy logic toolbox, which was designed specifically for this purpose. This interface allows users to specify the input of the system, including differential speed, traffic volume, residential density and the number of accidents in each traffic calming project. Figure 7 shows a screen shot of Prioria's user interface.

Prioria's user-interface is composed of three main sections, namely input, record and output. In the input section, the five textboxes designed are, the name of streets, daily traffic volume, accidents number, residential density and differential speed. Users have to insert the parameters related to a street study in the blank fields of the input sections. The allowed range of input variables is represented to users in the highlighted texts. After inserting the parameters, users must click the 'Submit' button to save the record. In the records section, users can delete or edit the content of a selected record by inserting the number of a record in the blank field. The output section was provided to show the results of the fuzzy inference system for a group of streets in the form of a table. The overall rating for each traffic calming project can be seen in the last column of this table, which represents the output of the expert system. In addition to these sections, two useful buttons were designed at the top of the GUI. By clicking the 'New Projects' button, users can delete current records, and by clicking the 'Edit Rules' button, they can edit the structure of the fuzzy rules or change the design of the membership functions.

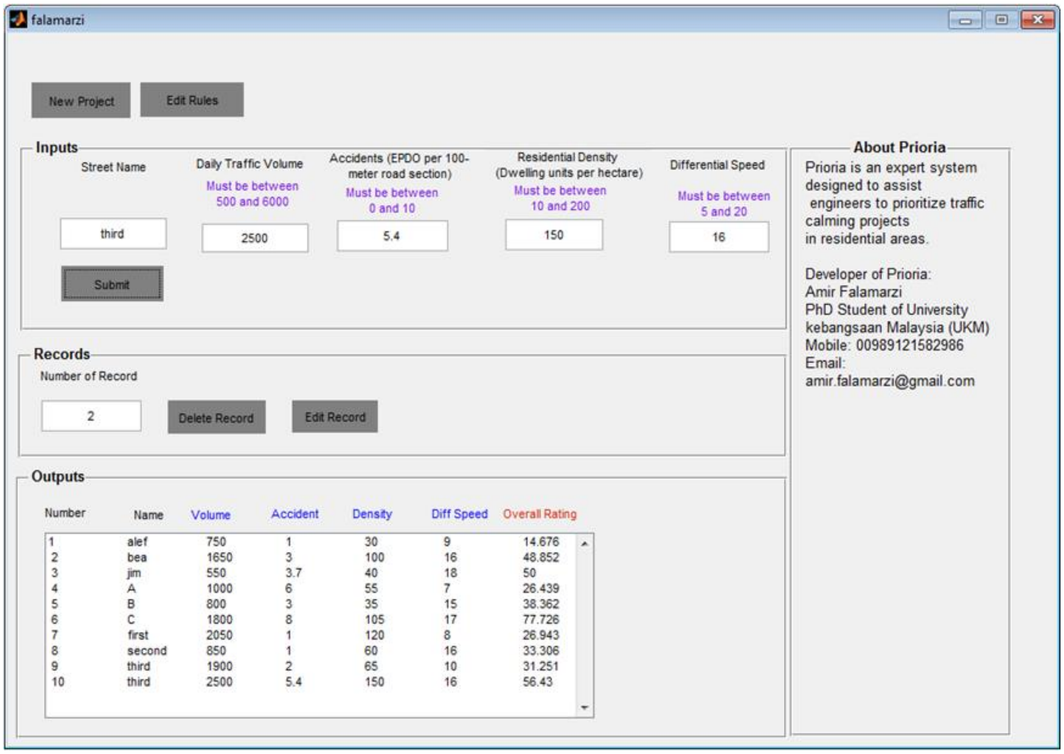


Figure 7 A screenshot of Prioria user-interface

5.0 SYSTEM TESTING

Because an expert system consists of domain knowledge, experience, reasoning and judgment, the process of verification and validation is extensive. Verification of an expert system aims to determine whether the system can work in accordance with its main specifications. The validation process analyses whether the expert system can conform to its requirements [31]. After constructing an expert system, running a real test can be used to verify and validate the capability of the system. Generally, system testing as a tool for the verification of expert system can be performed to assure knowledge engineers that the system works efficaciously [32]. The validation process can be carried out by comparing the output of the system with the results obtained from applying alternative methods, [33]. In this research, a number of residential streets in the city of Tehran were selected. The values of effective parameters related to each street were collected from the street database of the Tehran Traffic Organization.

After running the system and processing the input data, the output (which represents the overall rating of each street) was derived (as stated in Table 3). According to the results, the output of the system is dependent on the value of input parameters. Streets with a higher safety risk (streets with a higher number of accidents and greater differential speeds, are more vulnerable than the rest) gain a greater priority. The values of input parameters were presented to three domain experts (who were not part of the knowledge acquisition process). They were asked to prioritize the alternatives according to their individual judgments. Comparison of system results and expert recommendations showed that there was no significant difference between the priority structure proposed by the system and the expert's recommendations. The order of streets with high priorities was almost identical in both cases.

Table 3 The results of the system testing

No.	Density	Diff. Spd.*	DTV*	EPDO (per 100m of road)	O. Rating*	Rank
1	30	9	750	1	14.7	10
2	100	16	1650	3	48.9	4
3	40	18	550	3.7	51.1	3
4	55	7	1000	6	26.4	9
5	35	15	800	3	39.1	5
6	105	17	1800	8	77.7	1
7	120	8	2050	1	26.9	8
8	60	16	850	1	33.3	6
9	65	10	1900	2	32.5	7
10	150	16	2500	5.4	56.4	2

Diff. Speed= Differential Speed
DTV= Daily Traffic Volume
O. Rating= Overall Rating

6.0 SYSTEM EVALUATION

Evaluation of the system was carried out in order to assess the acceptance and usefulness of the proposed system by its potential users and domain experts. Evaluation of the expert system and the feedback received from users can be used for corrective measures to increase the performance of the system. The evaluation of Prioria was conducted with participation from end-users and domain experts. In addition to the evaluation of the effectiveness and usefulness of the system conducted by domain experts, the comments of end-users were equally important, as they serve as guidance for improving the quality of the system [17]. End-users include green or inexperienced engineers, students, decision-makers and those interested in finding the recommendations, according to their needs through employing the system. To evaluate the system, five domain experts and twenty potential users were asked to participate in a survey. The questions provided in this survey focused on the effectiveness and usefulness of the system. A 5 point Likert scale (5= strongly agree, 4= agree, 3=neutral, 2= disagree and 1=strongly disagree) was used to collect and analyse the respondent's answers. The results of the analysis for both groups of participants are presented in Table 4 below:

Table 4 The results of the system evaluation

No.	Questions	Response of End-users		Response of Domain experts		P-value
		Mean	S.D.	Mean	S.D.	
1	The system is user friendly	4.2	0.45	4.05	0.76	0.679
2	The system is pleasant to use	4.6	0.55	4.2	0.62	0.199
3	The system is easy to use	4.4	0.55	4.15	0.37	0.228
4	The system is easy to learn	4.6	0.55	4.25	0.64	0.273
5	The system runs command quickly	4	0.71	3.8	0.62	0.533
6	Technical errors has not occurred	4.2	0.45	4.25	0.64	0.871
7	Brings innovative approach to prioritize TC projects	4.4	0.55	4.5	0.51	0.704
8	The input variables are well defined	3.6	0.55	3.9	0.64	0.347
9	the whole system is useful	4.4	0.55	3.9	0.64	0.124
10	Recommending to other users	4.6	0.55	4.15	0.49	0.085

As shown in Table 4, the mean of the responses (both end-users and domain experts) is above four; which denotes that the evaluators were satisfied with the performance and usefulness of the system. For example, the majority of domain experts and end-users chose 'agreed' or 'strongly agreed' to recommend the system to other users. Furthermore, the results were analysed by T-test to compare the mean of the group's answers. As shown in Table 4, the difference between the answers of two groups was not statistically significant (p-value > 0.05). This means that both end-users and domain experts, who participated in the evaluation of the system, had similar opinions on this subject.

7.0 DISSCUSSION AND CONCLUSION

In this study, the development of an expert system to prioritize traffic calming projects was examined. Although the expert system was developed using

MATLAB, the customized graphical user interface was created to enhance user performance in utilizing the system. The system had the ability to prioritize a large number of alternatives and present results to users in the form of a list; which served as guidance for them when comparing alternatives. The proposed system had several advantages over conventional methods of prioritizing traffic calming projects. For example, in reality, we cannot accurately specify the boundary of traffic volume using conventional methods. Low or high traffic volumes cannot be defined by a specific number. However, with the employment of fuzzy logic membership functions, a range for different amounts of traffic volume (including low, medium and high) was proposed.

Furthermore, Prioria has the ability to process information instantaneously and deal with a large amount of data without complication. Since the form of membership functions and rules can be altered, the system is flexible for different decision-making models. In an attempt to verify and validate the system, a practical test was conducted. Comparison of the outputs provided by the system and recommendations derived from the judgments of experts revealed that there was no significant difference between the two answers. In addition, the system's evaluation was carried out through the participation of both potential users and domain experts. According to the results, the evaluators of the system confirmed that Prioria was useful and acceptable in different aspects, and they agreed to recommend the potency of the system to other users. In order to enhance the system, several recommendations for future projects are proposed as follows:

- Connecting the system to a database to store data related to streets for future use.
- Developing a multi-lingual (i.e., Chinese, Bahasa Malaya and Bahasa Indonesia) version of the application to enhance the use of the system and attract more users.
- Changing the application from being Windows-based to web-based can promote the effectiveness of the application and capture the interest of more users worldwide

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