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Application Zadeh's Implication in Designing Fuzzy Controller **Sh.A. Ahmadov**

Azerbaijan State Oil and Industry University (Baku, Azerbaijan)

For correspondence:

Shamil Ahmadov / e-mail: ahmadov.shamil@asoiu.edu.az

Abstract

The article investigates the problem of traffic signal control within the framework of a fuzzy logic approach, with particular emphasis on the application of Zadeh's fuzzy implication. The rapid development of artificial intelligence requires the processing of information of various types. Today, the mathematical foundation of artificial intelligence is based on binary logic and probability theory, which leads to information loss. According to the scientific literature, one of the theories that has contributed to the development of artificial intelligence is fuzzy logic. Based on logical inference and fuzzy implications, imprecise information can be effectively processed. For this reason, fuzzy implications are still widely used today. In this study, a conditional reasoning method based on fuzzy logic is employed and applied to controller design. Within the methodological framework, information processing is carried out using fuzzy inference, membership functions, and Zadeh's implication. During model development, real traffic conditions are taken into account, and parameters such as the number of vehicles passing during the green light (Arrival Vehicles), the number of vehicles waiting at the red light (Waiting Vehicle in Queue), weather variability (Humidity or Fog), and green light duration are used. Computer simulations are performed based on data obtained from the scientific literature and are analyzed using a new approach. As a result, it is shown that the proposed method is an effective approach for evaluating traffic congestion and improving the efficiency of traffic signal control systems.

Keywords: fuzzy logic, Zadeh implication, fuzzy controller, fuzzy reasoning, membership function, control traffic signals

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Qeyri-səlis kontrollerin dizaynında Zadənin qeyri-səlis implikasiyasının tətbiqi

Ş.A. Əhmədov

Azərbaycan Dövlət Neft və Sənaye Universiteti (Bakı, Azərbaycan)

Xülasə

Məqalədə yol hərəkəti siqnallarının idarə edilməsi problemi qeyri-səlis məntiq yanaşması çərçivəsində tədqiq olunub və xüsusilə Zadənin qeyri-səlis implikasiyasının tətbiqi araşdırılıb. Süni intellektin sürətli inkişafı müxtəlif təbiətli informasiyanın emalını tələb edir. Bu gün süni intellektin riyazi əsası binar məntiqə və ehtimal nəzəriyyəsinə əsaslanır. Bu da informasiya itkisinə səbəb olur. Elmi ədəbiyyata əsasən qeyd etmək olar ki, süni intellektin inkişafına təkan verən nəzəriyyələrdən biri qeyri-səlis məntiqdir. Məntiqi çıxarılış və qeyri-səlis implikasiyalar əsasında qeyri-dəqiq informasiya emal edilə bilər. Bu səbəbdən qeyri-səlis implikasiyalar bu gün də tətbiq edilir. Tədqiqatda qeyri-səlis məntiqə əsaslanan şərti məntiqi çıxarılış üsulu istifadə edilmiş və bu üsul kontroller dizaynına tətbiq olunmuşdur. Metodoloji yanaşma çərçivəsində qeyri-səlis mühakimə, mənsubiyyət funksiyaları və Zadə implikasiyası əsasında informasiya emalı həyata keçirilmişdir. Modelin işlənməsi zamanı real yol hərəkəti şəraiti nəzərə alınaraq yaşıl işıqda keçən nəqliyyat vasitələrinin sayı, qırmızı işıqda gözləyən nəqliyyat vasitələrinin sayı, hava şəraitinin dəyişkənliyi (rütubət və duman) və yaşıl işığın müddəti kimi parametrlər istifadə olunmuşdur. Kompüter simulyasiyaları elmi ədəbiyyatdan götürülmüş verilənlər əsasında aparılmış və yeni yanaşma ilə təhlil edilmişdir. Nəticə olaraq, təklif olunan metodun işıqforların idarə edilməsində tıxacın qiymətləndirilməsi və yol hərəkətinin daha səmərəli tənzimlənməsi üçün effektiv bir yanaşma olduğu göstərilmişdir.

Açar sözlər: qeyri-səlis məntiq, Zadə implikasiyası, qeyri-səlis kontroller, qeyri-səlis mühakimə, mənsubiyyət funksiyası, işıqforların idarə edilməsi

Применение импликации Заде при проектировании нечеткого контроллера

Ш.А. Ахмедов

Азербайджанский Государственный Университет Нефти и Промышленности
(Баку, Азербайджан)

Аннотация

В статье исследуется проблема управления светофорными сигналами в рамках подхода нечеткой логики, при этом особое внимание уделяется применению нечеткой импликации Заде. Быстрое развитие искусственного интеллекта требует обработки информации различного характера. В настоящее время математическая основа искусственного интеллекта базируется на бинарной логике и теории вероятностей, что приводит к потере информации. Согласно научной литературе, одной из теорий, способствовавших развитию искусственного интеллекта, является нечеткая логика. На основе логического вывода и нечетких импликаций возможно обработка неточной информации, поэтому нечеткие импликации продолжают активно применяться и сегодня. В исследовании использован метод условного логического вывода на основе нечеткой логики, который применяется при проектировании контроллера. В рамках методологического подхода осуществлялась обработка информации на основе нечеткого вывода, функций принадлежности и импликации Заде. При разработке модели учитывались реальные условия дорожного движения и использовались такие параметры, как количество транспортных средств, проезжающих на зелёный сигнал светофора, количество транспортных средств, ожидающих на красный сигнал, изменчивость погодных условий (влажность или туман), а также продолжительность зелёного сигнала. Компьютерное моделирование проводилось на основе данных, взятых из научной литературы, и анализировалось с использованием нового подхода. В результате показано, что предложенный метод является эффективным инструментом для оценки транспортной загруженности и более эффективного регулирования дорожного движения в системах управления светофорами.

Ключевые слова: нечеткая логика, импликация Заде, нечеткий контроллер, нечеткое рассуждение, функция принадлежности, управление светофора

Introduction

Fuzzy implication is an extended form of the classical, binary implication, which plays an important role in the development of artificial intelligence, in the process of approximate reasoning. Implications consist of a condition and a conclusion and are considered to be basic operations in fuzzy logic and approximate reasoning. Choosing the right fuzzy implication for each specific application is a complex task. This problem [1,2] has been discussed. There are numerous fuzzy implications, the creation of which is related to human judgment. In turn, judgment is one of the areas of artificial intelligence that is being studied and developed. Since it is widely used in inference and depends on the nature of information. If the uncertainty in information is related to chance, lack of information, then probability theory is an effective approach, and if it depends on the inaccuracy of information, then fuzzy logic judgment is an effective approach. The first research in this field belongs to Professor Zadeh [1]. The concept of fuzzy judgment was also first given in this article.

Fuzzy implications, which form the basis of approximate judgment, are used to construct relation matrices based on rules. In binary logic, production rules are more rigid than those described in fuzzy logic, and are characterized by information loss. Fuzzy logic is a powerful tool for describing information through fuzzy implications. This is confirmed by the existing scientific literature [3]. However, there are still problems that need to be studied and improved. Various operations on fuzzy implications and matrices based on them are investigated in numerous scientific works. It should be noted that when processing

fuzzy relation matrices, the combination operations and the type of implication affect the result. For example, fuzzy implications cannot be used to process imperfect information or information based on probability and fuzzy uncertainty. There are few works in this area.

There is a growing need for new approaches that extend the functionality of fuzzy implication to Z-number-based implication. Z-numbers allow modeling both the uncertainty and the validity of information simultaneously. This supports the development of logical judgment. Many existing methods of fuzzy inference are based on the fuzzy relation matrix and Zadeh's Compositional Inference Rule (CRI). Thus, there is a need to improve the approaches established in [4-6]. In the scientific literature, there are fuzzy inference methods that do not use Zadeh's CRI and use the degree of similarity. In [7], fuzzy production rules, fuzzy inference methods, and six fuzzy inference methods based on similarity are compared. In similarity based approach [8], the similarity between the current data and the data on the left side of the rules is calculated. For the right side (outcome), a linear combination of weights is used. The development of this method is of interest because it involves a combination of fuzzy and probabilistic uncertainties [8]. This approach is also characterized by simplicity [8], the absence of the need for predefined rules. The system evolves as new rules are added, and there is no need to rewrite the algorithm [9]. However, if the given rules are not complete and correct, they lead to incorrect results, the results become approximate, and extrapolation to new situations is not possible. For this reason, the correct use of fuzzy implication is

particularly necessary. In this sense, the application of fuzzy implication is of particular interest. Let us consider the use of one of the famous implications, Zadeh's fuzzy implication, in controller design.

Purpose of the work

In this study, a new fuzzy logic inference approach based on Zadeh implication is presented. Based on this approach, the traffic signal control problem is investigated. To test the approach presented by, data from a problem existing in the scientific literature were used. This approach allows determining the number of vehicles passing at a green light, the number of vehicles waiting at a red light, and the green light duration taking into account weather variability. Works based on the creation of controllers based on fuzzy logic are available in the scientific literature [10-12] and in practice (for example, Samsung washing machines are widely used today). The creation of the controller based on Zadeh's own implication is of particular interest.

Proposed algorithm

The main steps of the proposed Zadeh's implication based logical inference algorithm (or designing fuzzy controller algorithm) are as follows:

1. To identify input and output variables.
2. To define linguistic terms of inputs and output variables.
3. To describe the linguistic terms as fuzzy set (obtaining membership function) and formulate fuzzy model.
4. Using Zadeh's fuzzy implication to create fuzzy relation on production rules.

This step is to define for each rule a fuzzy relation matrix R_s , $s = 1 \dots 7$.

5. The membership function [13] of the relation is defined in accordance with Lotfi A. Zadeh's implication [14,15]:

$$I(a,b) = \max(1-a, \min(a,b)), \quad T = \min(a,b)$$

6. To define a composed fuzzy relation matrix $R = \cup R_s, s = 1, \dots, n$ according as logical connective "and".

7. To calculate the membership function of the output defined using the compositional rule of inference:

$$\mu_Q(a,b) = \max_q \min[\mu_P(p), \mu_R(p,q)]$$

8. To calculate defuzzified value of the output.

Statement of the problem and research method. Numerical example

Data about the controller in which Zadeh's implication is applied is taken from [14]. The number of input variables of this controller is 3, and the number of output variables is one.

The input variables are the number of vehicles passing on the green light (AV- Arrival Vehicle), the number of vehicles waiting on the red light (QV- Waiting Vehicle in Queue), and the weather variability (F- Humidity or Fog).

Step 1. The output variable is the green light duration (GD). This variable provides the required extension time for the green light on the arrival side. Input and output variable and their values and names of linguistic variables on one are given below:

Arriving vehicle: (ranges, linguistic variables) = ((0-10, Less), (7-25, Medium), (20-50));

Queuing vehicle: (ranges, linguistic variables) = ((0-10, Less), (7-25, Medum), (20-50));

Green light duration:(ranges, linguistic variables) = ((0-10, Short), (8-30, Medum), (25-60)).

Fog:(ranges, linguistic variables) = ((1000-1500, Low), (400-1200, Medum), (50-500));

Step 2. Analytical expression of membership functions for the arriving vehicle (car) and queuing vehicle(car) are given below:

$$\mu_{Less}(x) = \begin{cases} \frac{x}{7}, & 0 < x \leq 7 \\ \frac{10-x}{3}, & 7 \leq x \leq 10 \\ 0, & x \leq 0 \text{ or } x \geq 10 \end{cases} \quad \mu_{Medium}(x) = \begin{cases} \frac{x-7}{8}, & 7 < x \leq 15 \\ \frac{25-x}{10}, & 15 \leq x \leq 25 \\ 0, & x \leq 7 \text{ or } x \geq 25 \end{cases} \quad \mu_{High}(x) = \begin{cases} \frac{x-20}{15}, & 20 < x \leq 35 \\ \frac{50-x}{15}, & 35 \leq x \leq 50 \\ 0, & x \leq 35 \text{ or } x \geq 50 \end{cases}$$

Analytical expression of membership functions for the Fog (in meters) are as follow:

$$\mu_{Low}(x) = \begin{cases} \frac{x-1000}{150}, & 1000 < x \leq 1150 \\ \frac{1500-x}{350}, & 1150 \leq x \leq 1500 \\ 0, & x \leq 1000 \text{ or } x \geq 1500 \end{cases} \quad \mu_M(x) = \begin{cases} \frac{x-400}{300}, & 400 < x \leq 700 \\ \frac{1200-x}{500}, & 700 \leq x \leq 1200 \\ 0, & x \leq 400 \text{ or } x \geq 1200 \end{cases} \quad \mu_H(x) = \begin{cases} \frac{x-50}{230}, & 50 < x \leq 280 \\ \frac{500-x}{220}, & 280 \leq x \leq 500 \\ 0, & x \leq 50 \text{ or } x \geq 500 \end{cases}$$

Membership functions for the green light duratin (in sec) are describes as follow:

$$\mu_{Short}(x) = \begin{cases} \frac{x}{7}, & 0 < x \leq 7 \\ \frac{10-x}{3}, & 7 \leq x \leq 10 \\ 0, & x \leq 0 \text{ or } x \geq 10 \end{cases} \quad \mu_{Medium}(x) = \begin{cases} \frac{x-8}{10}, & 8 < x \leq 18 \\ \frac{30-x}{12}, & 18 \leq x \leq 30 \\ 0, & x \leq 8 \text{ or } x \geq 30 \end{cases} \quad \mu_{Long}(x) = \begin{cases} \frac{x-25}{10}, & 25 < x \leq 35 \\ \frac{60-x}{25}, & 35 \leq x \leq 60 \\ 0, & x \leq 25 \text{ or } x \geq 60 \end{cases}$$

3. Step 3. Graphical representation of linguistic terms of inputs and output of the model are given in Figure 1.

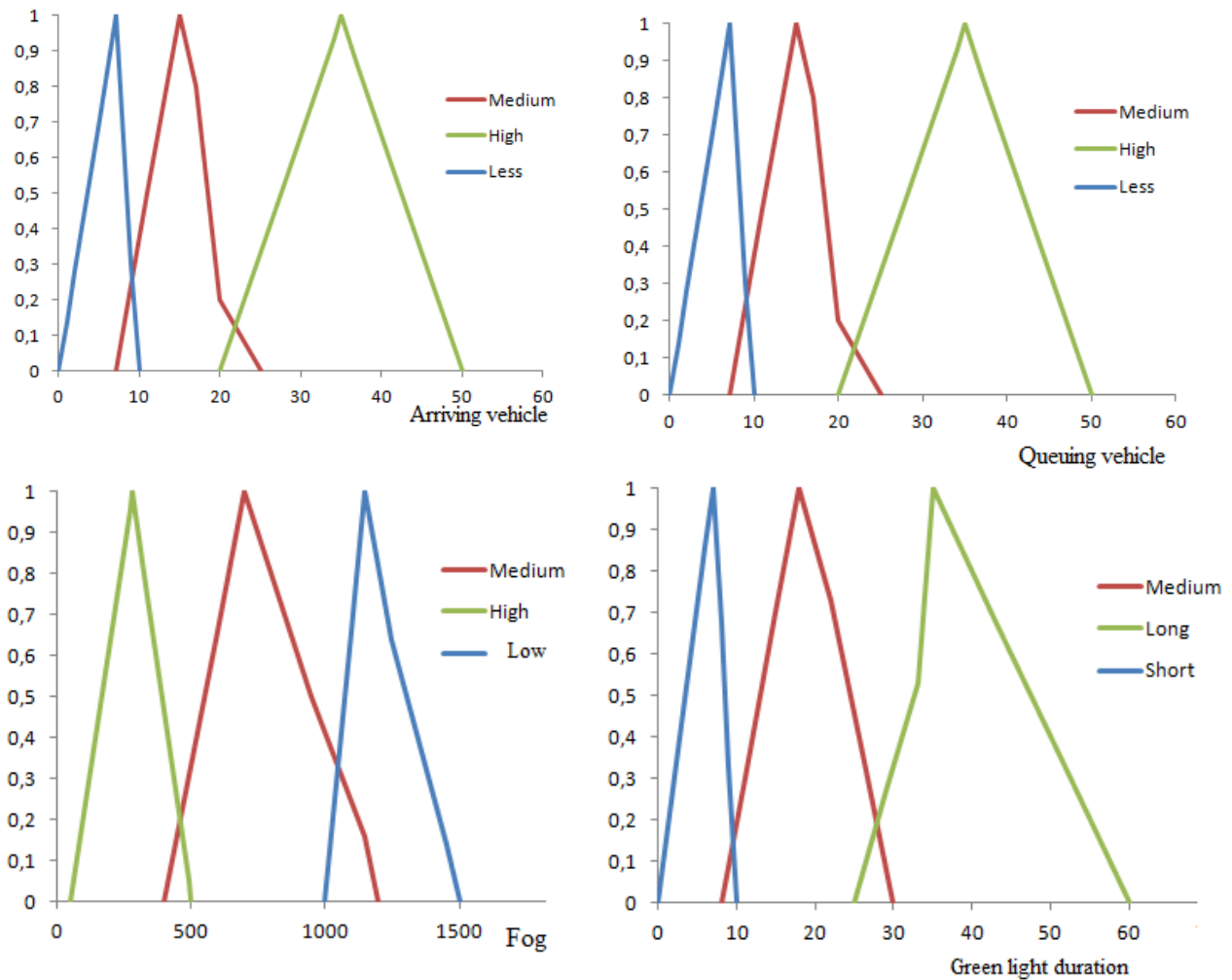


Figure 1 – Graphical representation of linguistic terms of inputs and output of the model (computer simulation)

Created model using production rules are described as follow:

- IF arriving vehicle is HIGH and queuing vehicle is LESS and Fog is LOW THEN Green light duration is SHORT;
- IF arriving vehicle is HIGH and queuing vehicle is LESS and Fog is MEDIUM THEN Green light duration is MEDIUM;
- IF arriving vehicle is HIGH and queuing vehicle is LESS and Fog is HIGH THEN Green light duration is LONG;

- IF arriving vehicle is MEDIUM and queuing vehicle is LESS and Fog is LOW THEN Green light duration is SHORT;
- IF arriving vehicle is MEDIUM and queuing vehicle is LESS and Fog is HIGH THEN Green light duration is MEDIUM;
- IF arriving vehicle is MEDIUM and queuing vehicle is HIGH and Fog is LOW THEN Green light duration is LONG;
- IF arriving vehicle is LESS and queuing vehicle is LESS and Fog is LOW THEN Green light duration is SHORT.

Goal is to determine Green light duration approach based on Zadeh's implication.
 as the result of proposed fuzzy reasoning

Step 4. For solving this problem we create fuzzy relation on the 7 rules. Calculated relation matrices are given below:

Relation matrix 1

	0	0,43	0,86	1	0,67	0,33	0
0	1	1	1	1	1	1	1
0,14	0,86	0,86	0,86	0,86	0,86	0,86	0,86
0,28	0,72	0,72	0,72	0,72	0,72	0,72	0,72
0,71	0,29	0,43	0,71	0,71	0,67	0,33	0,29
0,64	0,36	0,43	0,64	0,64	0,64	0,36	0,36
0,14	0,86	0,86	0,86	0,86	0,86	0,86	0,86
0	1	1	1	1	1	1	1

Relation matrix 2

	0	0,3	0,7	1	0,73	0,36	0
0	1	1	1	1	1	1	1
0,14	0,86	0,86	0,86	0,86	0,86	0,86	0,86
0,28	0,72	0,72	0,72	0,72	0,72	0,72	0,72
0,71	0,29	0,3	0,7	0,71	0,71	0,36	0,29
0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
0,16	0,84	0,84	0,84	0,84	0,84	0,84	0,84
0	1	1	1	1	1	1	1

Relation matrix 3

	0	0,27	0,53	1	0,68	0,36	0
0	1	1	1	1	1	1	1
0,14	0,86	0,86	0,86	0,86	0,86	0,86	0,86
0,28	0,72	0,72	0,72	0,72	0,72	0,72	0,72
0,71	0,29	0,29	0,53	0,71	0,68	0,36	0,29
0,77	0,23	0,27	0,53	0,77	0,68	0,36	0,23
0,05	0,95	0,95	0,95	0,95	0,95	0,95	0,95
0	1	1	1	1	1	1	1

Relation matrix 4

	0	0,43	0,86	1	0,67	0,33	0
0	1	1	1	1	1	1	1
0,14	0,86	0,86	0,86	0,86	0,86	0,86	0,86
0,28	0,72	0,72	0,72	0,72	0,72	0,72	0,72
0,71	0,29	0,43	0,71	0,71	0,67	0,33	0,29
0,64	0,36	0,43	0,64	0,64	0,64	0,36	0,36
0,14	0,86	0,86	0,86	0,86	0,86	0,86	0,86
0	1	1	1	1	1	1	1

Relation matrix 5

	0	0,3	0,7	1	0,73	0,36	0
0	1	1	1	1	1	1	1
0,14	0,86	0,86	0,86	0,86	0,86	0,86	0,86
0,28	0,72	0,72	0,72	0,72	0,72	0,72	0,72
0,71	0,29	0,3	0,7	0,71	0,71	0,36	0,29
0,77	0,23	0,3	0,7	0,77	0,73	0,36	0,23
0,05	0,95	0,95	0,95	0,95	0,95	0,95	0,95
0	1	1	1	1	1	1	1

Relation matrix 6

	0	0,27	0,53	1	0,68	0,36	0
0	1	1	1	1	1	1	1
0,33	0,67	0,67	0,67	0,67	0,67	0,67	0,67
0,66	0,34	0,34	0,53	0,66	0,66	0,36	0,34
1	0	0,27	0,53	1	0,68	0,36	0
0,64	0,36	0,36	0,53	0,64	0,64	0,36	0,36
0,14	0,86	0,86	0,86	0,86	0,86	0,86	0,86
0	1	1	1	1	1	1	1

Step 5. Fragment of graphical representation of the rules(relation 6) is given in figure 2.

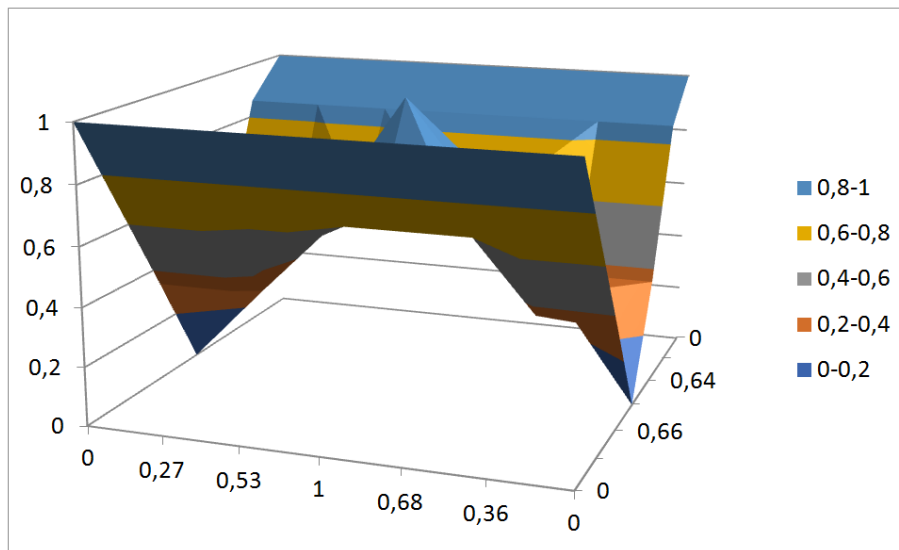


Figure 2 – Graphical representation of the sixth rule (computer simulation)

Relation matrix7

	0	0,43	0,86	1	0,67	0,33	0
0	1	1	1	1	1	1	1
0,14	0,86	0,86	0,86	0,86	0,86	0,86	0,86
0,28	0,72	0,72	0,72	0,72	0,72	0,72	0,72
0,71	0,29	0,43	0,71	0,71	0,67	0,33	0,29
0,64	0,36	0,43	0,64	0,64	0,64	0,36	0,36
0,14	0,86	0,86	0,86	0,86	0,86	0,86	0,86
0	1	1	1	1	1	1	1

Step 6. A composed fuzzy relation matrix $R = \cup R_s, s = 1, \dots, n$ according as logical connective “and” is defined as the following form:

1	1	1	1	1	1	1
0,86	0,86	0,86	0,86	0,86	0,86	0,86
0,72	0,72	0,72	0,72	0,72	0,72	0,72
0,29	0,43	0,71	1	0,71	0,36	0,29
0,5	0,5	0,7	0,77	0,73	0,5	0,5
0,95	0,95	0,95	0,95	0,95	0,95	0,95
1	1	1	1	1	1	1

Step 7. The membership function of the output is defined using the compositional rule of inference:

IF arriving vehicle is LESS and queuing vehicle is HIGH and Fog is LOW THEN Green light duration (GLD) is SHORT or
 $GLD = (0.5/0 + 0.5/3 + 0.71/6 + 0.71/7 + 0.71/8 + 0.5/9 + 0.5/10)$.

Step 8. Obtained result is subnormal fuzzy set (see figure 3). To defuzzify a subnormal set, we convert it to a normal fuzzy set as follow:

$$GLD = \frac{\sum_{i=1}^7 \mu_i}{\sum_{i=1}^7 \max(\mu_i)} = (0,70422535 \cdot 2/0 + 0,70422535 \cdot 2/3 + 1/6 + 1/7 + 1/8 + 0,70422535 \cdot 2/9 + 0,70422535 \cdot 2/10)$$

Here, the “SUM” sign does not express a SUM, it indicates that the fuzzy set is discrete.

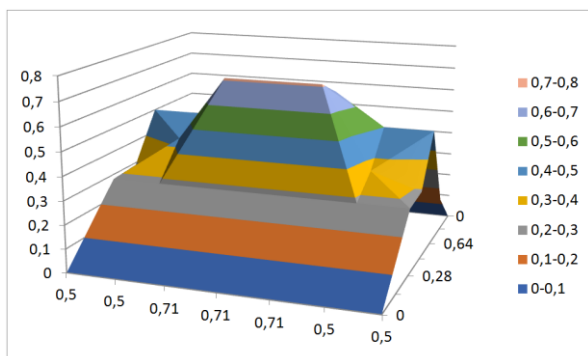


Figure 3 – Obtained result as subnormal fuzzy set (computer simulation)

Result of defuzzification is determined using center of gravity method:

$$GLD = \frac{\sum_{i=1}^7 \mu_i x_i}{\sum_{i=1}^7 \mu_i} = 6,2736 \text{ sec.}$$

Thus, IF arriving vehicle is LESS and queuing vehicle is HIGH and Fog is LOW THEN Green light duration (GLD) is 6.27 sec.

The approach proposed in this article may allow for a better estimation of the traffic jam.

Conclusion

The article proposes a logical inference algorithm based on Zadeh's fuzzy implication. The proposed approach allows designing fuzzy controllers based on fuzzy rules. As a numerical example, the problem of traffic jam estimation is solved. The created controller allows analyzing Green light duration. This problem can be solved by increasing the number of data in the antecedents of the rules. The advantage of this method over the interpolation-based method is that it allows logical inference when adding new rules and removing rules from the system. The proposed approach can be used for decision-making in any field under conditions of information inaccuracy. The approach proposed in this article can be used for traffic jam estimation in traffic control.

Conflict of Interests

The author declares there is no conflict of interests related to the publication of this article.

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