Fuzzy Logic Controller for Vehicles Recommended Speed

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Abstract

This paper examines the design and application of a Recommended Vehicle Speed (RVS) system based on Fuzzy Logic Controllers (FLCs) to improve traffic conditions and safety on motorways and highways. Unlike traditional Variable Speed Limit (VSL) systems, the RVS system focuses on actively recommending vehicle speeds to prevent or reduce traffic congestion. The system uses interconnected FLCs, sensors and a wireless communication system to calculate recommended speeds and transmit them to vehicles and drivers. The proposed RVS algorithm uses Mamdani-type FLCs, where first FLC estimates traffic congestion based on the number of incoming and outgoing vehicles, while second FLC calculates the recommended speed based on distance between the vehicle and traffic jam road section. Simulation results show the effectiveness of the system which is capable to dynamically adjust the recommended speed, improve traffic flow, reduce traffic congestion, and therefore to enhance road safety.

Keywords: *Fuzzy Logic Controller, Recommended Vehicle Speed, Traffic Jams, Traffic Control*

1 Introduction

The existing traffic infrastructure was designed with the clear intention to ensure a smooth, safe and optimal flow of motor vehicles, as well as other traffic participants. Considering the diversity of traffic participants, the traffic infrastructure must provide minimum conditions that allow all participants to flow smoothly. This is often a very complex task, bearing in mind the age of the roadways, as well as the increase in the number of vehicles of newer production date, which are functionally more advanced than the vehicles that were in circulation at the time of the design of the roadway infrastructure.

The problems of circulation of participants in the traffic occur in many situations, while they are especially pronounced in big cities, as well as on the access roads leading to cities center.

This paper investigates the possibility of improving traffic conditions on roads reserved for motor vehicles, as well as on highways. Attention is devoted to the possibilities of preventing so-called traffic jams (gridlock), where a large number of motor vehicles move slowly or are completely stopped and cannot move freely. Therefore, this paper focuses on situations where traffic flow comes to a complete halt, crawls at a very slow pace due to congestion or flow speed is limited due to congestion. This happens when the number of vehicles trying to use the road exceeds its capacity or it is caused by accidents, road closures, or blocked road sections. Approaches to toll booths, border crossings, intersections, as well as approaches to larger cities are particularly interesting. The solution proposed in this work is based on the application of several interconnected Fuzzy Logic Controllers (FLC), sensors and infrastructure for wireless data communication.

The goal is to estimate the required vehicle speed in order to avoid a traffic jam and to transmit information about the recommended vehicle speed to an autonomous vehicle, a semi-autonomous vehicle or a driver, via means of

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traffic signalization. The term traffic jam is seen as a stoppage in traffic, slow traffic flow or constant speed traffic flow with the presence of an increased number of vehicles, usually on highways with a larger number of lanes, when all lanes are full. The proposed approach should enable constant speed of the traffic flow on a section that is often full of traffic jams and an excessive number of vehicles.

This paper is organized as follows: Section 2 contains the introspection to previous work, while Section 3 gives essential idea description, as well as some technical details of implementation. Section 4 contains simulation results and explanations. Finally, Section 5 gives conclusions and future work options.

2 Previous work

In [1] the problem of controlling speed limits is tackled. The paper examines the use of a Variable Speed Limit (VSL) control system which is one of the most used Intelligent Transportation Systems (ITS). A described case study deals with managing car speeds on 2-lane freeway, when multiple vehicles are interconnected in order to reduce traffic congestion and improve the road network's operational and environmental efficiency. The case study takes into account multiple vehicle parameters, driving style (slow, normal, aggressive) and pays attention to fuel consumption. A comparison between rule-based VLS, fuzzy VLS and no VLS at all is given. It is concluded that proposed fuzzy-based VSL system outperforms other approaches and enhances both operational and environmental performances of the road network.

Paper [2] proposes a fuzzy expert system for setting highway speed limits, specifically tailored for different road conditions. Drawing on the expertise of multiple practitioners, six key variables influencing speed limits were identified as inputs for the fuzzy system. Through simulated highway scenarios, expert system judgment, membership functions and fuzzy rules, the system were developed to capture the uncertainty inherent in speed limit selection. This paper contributes to the field by providing a systematic approach to account for uncertainty in speed limit setting and offering a practical tool for decision-makers to enhance highway safety. In this case, a fuzzy expert system is used to overcome the issue by utilizing the expert system knowledge and data to obtain highway speed limit values that have been organized into structured frameworks.

Traffic control using fuzzy logic is an effective approach in dealing with traffic flow at road junctions as it has been used for this purpose since its creation, and these systems have been proven to work very well. The paper [3] presents a literature review on the application of fuzzy control in traffic management, paying attention to its ability to cope with imprecise data and its perspective of increasing traffic junction efficiency.

In [4] the speed recommender development addresses some of the subjective perceptions of the driver and includes several other factors. By using intelligent expert system based on fuzzy logic, it is possible to recommend suitable speeds considering road geometry, weather conditions, and driver preferences. The paper concludes by discussing the potential impact of the proposed system on improving overall traffic safety and efficiency.

Some researchers have used Mamdani type fuzzy logic controller for their VLS research [5]. The distance and speed are used as the variables for the system. This approach can calculate the use of the vehicle's brakes to achieve optimal speed.

Most papers reviewed in this section deal with the introduction of VLS systems, which are related to limiting the maximum speed of vehicles. The impact of the application of such systems on fuel consumption, vehicle performance and, in general, on the performance of the entire traffic system is positive. Unlike the described solutions, investigation presented in this paper deals with a system for recommending vehicle speed (certainly below maximal speed limit) with the aim of preventing or reducing traffic congestions.

3 Recommended Vehicle Speed Based on Multiple Connected FLCs

In contrast to the previously investigated solutions for Variable Speed Limit (VSL), this research deals with the development of the idea of a system for Recommended Vehicle Speed (RVS). The RVS value must certainly not exceed the current speed limit or any other speed restrictions dictated by local traffic regulations. Both, VSL and RVS controller units can operate in parallel or in serial connection. The proposed idea of RVS takes into account the condition of the road section to which the motor vehicle is directed, (number of vehicles entering or exiting that road section). The idea also takes into account the feasibility of the technical solution of the idea (implementation), from the point of the price and the availability of the necessary hardware components. So, general assumption is that the implementation of the solution should be cheap, technically possible and feasible. The RVS idea, like the VSL, was also realized using the Mamdani-type FLC [7], although different approaches are also possible. Realization of RVS requires multiple FLCs in serial and parallel connection. The basic idea of RVS operation is presented in Fig. 1.

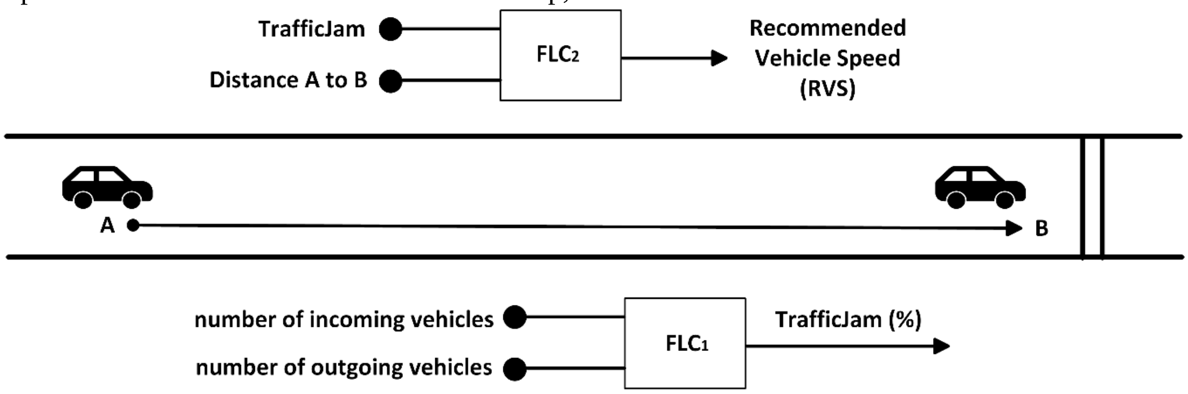

Fig. 1. Basic scheme of the system for Recommended Vehicle Speed

FLC_1 unit is located in a road section (B in Fig. 1) which is suitable for traffic jam assessment. This implies that road section B is often subject to traffic jams or an excessive number of vehicles, which limit the speed and freedom of movement of vehicles in terms of the possibility to change lanes, overtake, etc. There are two inputs to FLC_1: Number of Incoming Vehicles (NIV) and Number of Outgoing Vehicles (NOV), and the values of both inputs are measured using sensors. The output value of FLC_1 is traffic jam assessment in percents. Unlike FLC_1, which is stationary, FLC_2 is ideally located in the vehicle (A in Fig. 1), so the position of FLC_2 is not stationary. In a less ideal case, FLC_2 is located at one or more stationary roadside positions. The output value of FLC_1 is also one of the two input values of FLC_2, thus achieving a serial connection. The second input value of FLC_2 is the distance from point A to point B (see Fig. 1).

Fig. 2 shows connections of FLCs when there are multiple FLC_2 units. Output of every FLC_2 unit is recommended vehicle speed (RVS).

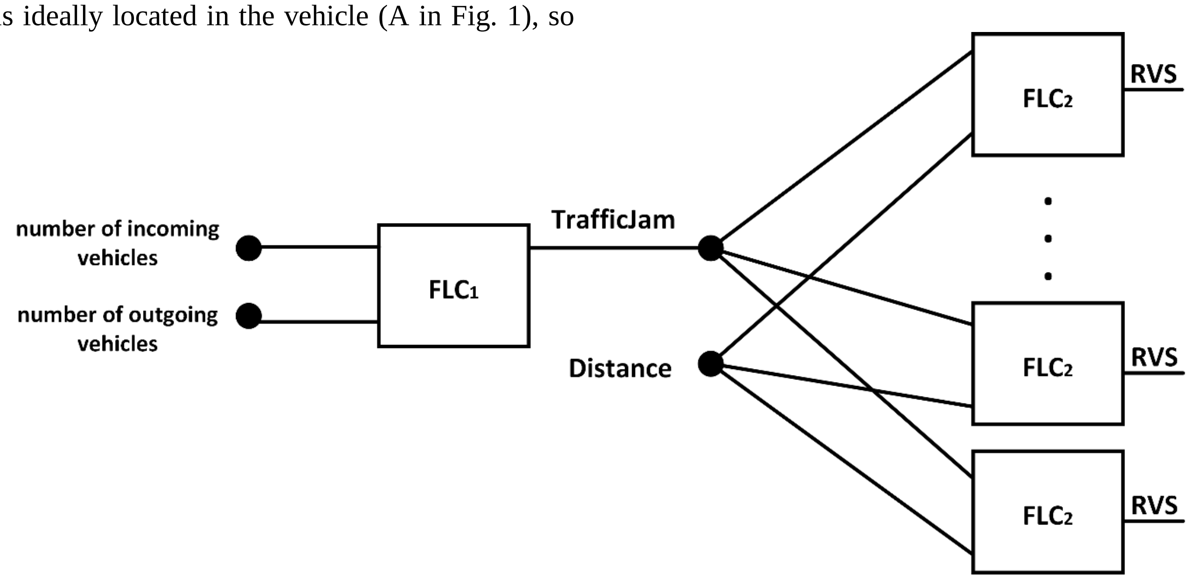

Fig. 2. FLCs in Serial/Parallel Connection

There are 16 fuzzy rules in FLC_2 and nine rules in FLC_1. In order to explain main idea, rule sets of FLC_1 and FLC_2 are given in a form of pseudo rules in Table 1.

Table 1. FLC Rules

No.	Rule	Origin
1.	If NIV=NOV THEN TRAFFICJAM [unlikely] OR [probable] OR [certain]	FLC_2
2.	IF TRAFFICJAM [unlikely] THEN SPEED [fast]	FLC_1
3.	IF DISTANCE [close] AND TRAFFICJAM [probable] OR [certain] THEN SPEED [moderate] OR [slow]	FLC_1
4.	IF DISTANCE [medium] AND TRAFFICJAM [certain] OR [probable] THEN SPEED [moderate]	FLC_1
5.	IF DISTANCE [far] AND TRAFFICJAM [probable] OR [certain] THEN SPEED [moderate] OR [fast]	FLC_1

Rule 1 from Table 1 ensures that the constant number of vehicles present on the road section affects that the traffic jam assessment value is increased on that road section. This corresponds to many real situations, in which there is no stoppage or significant deceleration, but the number of vehicles prevents pleasant or completely safe driving. This is the case on access roads to larger cities, highway junctions, etc. Rules 2 – 5 from Table 1, ensures that RVS is constant as much as possible.

Proposed solution was initially implemented in FLC Editor developed by G. Gecin and V. Brtka on Technical Faculty “Mihajlo Pupin”, Zrenjanin, Serbia. The editor is comparable to Fuzzy Logic Toolbox editor in Matlab [8]. This editor enables the application of four pairs of frequently used T-norms and co-norms. Three defuzzification methods are also available. Several parametric types of membership functions are available (trimf, trapmf, gaussmf). Fuzzy inference engine is of Mamdani type and uses the approach of discretizing continuous functions and operations on discretized values instead of computing the continuous membership function of consequent for each fuzzy rule.

The aggregated membership function B' is calculated by (1).

$$B' = \bigcup_{i=1}^{n} B_i' \qquad \ldots(1)$$

In (1), n is a rule count, while B_i' is a consequent of the i-th rule.

Defuzzyficaton method is based on calculation of a set Y^0, which contains those elements $y^0$of the output domain space Y, for which the value of membership function B' is maximal, given by (2).

$$Y^0 = \left\{ y^0 \middle| \mu_{B'}(y^0) = \max_{y \in Y} \mu_{B'}(y) \right\} \qquad ..(2)$$

Finally, defuzzified (crisp) output value y^C is calculated by (3).

$$y^C = \frac{y^0_{left} + y^0_{right}}{2} \qquad ...(3)$$

In (3) y^0_{left} and y^0_{rigt} are first and last output domain values from Y^0, respectively.

The discretization procedure enables operations on membership functions to be performed using operations on 2D arrays, thus reducing the complexity of calculations. Also, discretization requires determination of steps (precision) during discretization. It was found that reducing the discretization step does not necessarily affect the accuracy of FLC operation.

4 Simulation Results

In the previous section, the important details of the implementation of the idea of determining the RVS were presented. For the sake of a deeper analysis of the usability of the proposed RVS system, simulations were performed that include varying one input while the other input is constant. The predicted ranges of input values are from [0,1,...,100] for simplicity. Naturally, input values can be scaled or normalized, which increases the system's robustness. Same value range is adopted for output values.

Fig. 3 gives graphical representation of FLC_1 outputs.

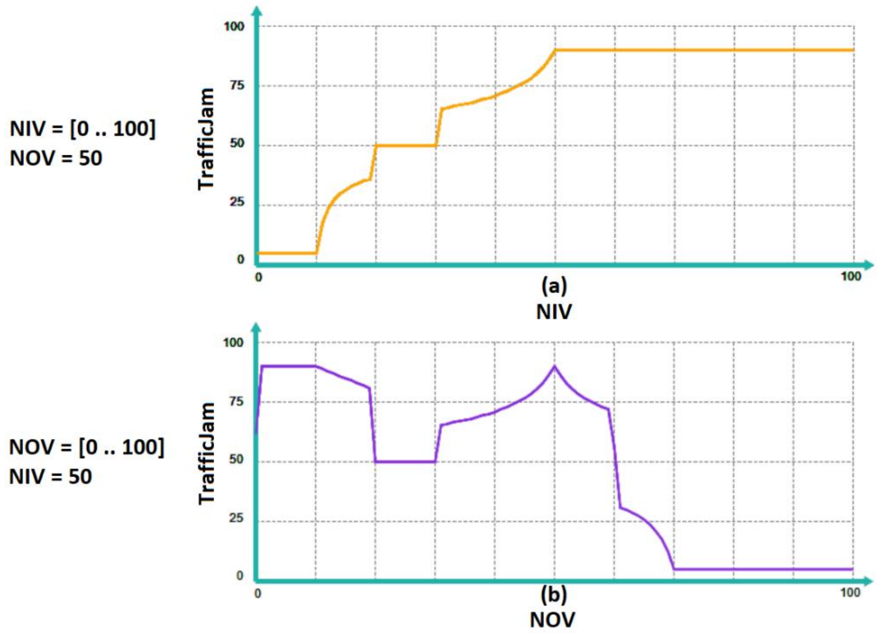

Fig. 3. FLC_1 Simulation Results

Fig. 3a shows the influence of varying NIV value, with a constant value of NOV, on the traffic jam assessment. Considering that the NOV value is a constant (50), the interesting part to analyze is the traffic jam assessment value for values of NIV≤50. An increase in the value of traffic jam assessment is expected, but the configuration of fuzzy rules allows it not to be constant (straight line), but to reach maximum values or stagnate in some situations (plateaus on the graph). The graph in Fig. 3a shows the property of convexity, which is a desirable property. It is shown that an increase in NIV results in an expected increase of traffic jam assessment value. Similarly, Fig. 3b shows the influence of varying NOV, with a constant value of NIV, on the traffic jam assessment. This non-convex function graph shows the expected decrease in the traffic jam assessment value, with an additional maximum reached for NOV=50. This is the desired result, and the intention is that the system behaves in such a way that for a constant number of vehicles (NIV=NOV), the road section is viewed as a traffic jam point.

Fig. 4 gives graphical representation of FLC_2 outputs.

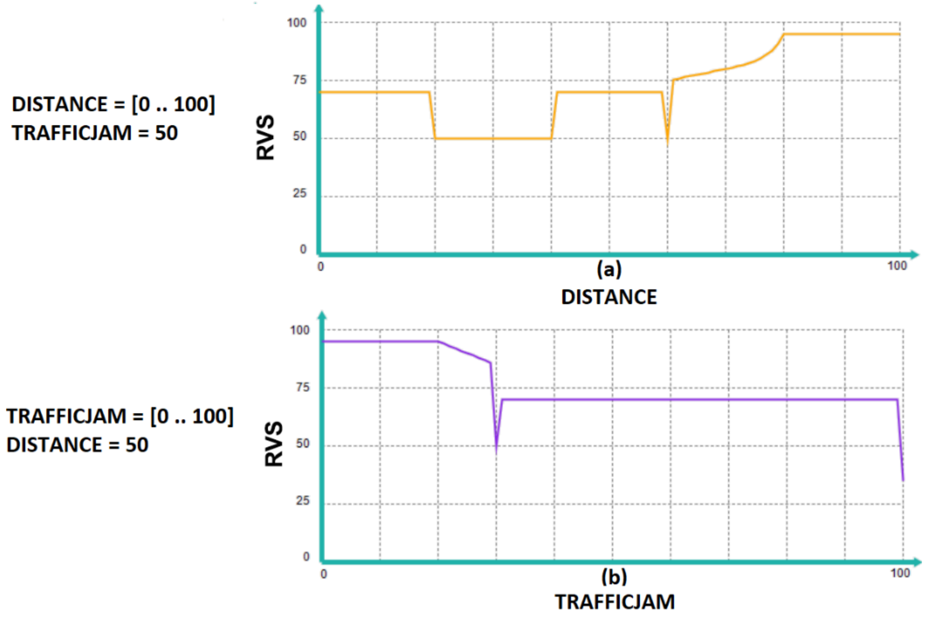

Fig. 4. FLC_2 Simulation Results

From the graph in Fig. 4a, it can be seen that the greater the distance to the traffic jam road section, the higher the recommended speed. Varying the value of traffic jam assessment, while the distance is constant, (see Fig 4b) expectedly reduces the value of the recommended speed. Here, one can clearly see the tendency for the recommended speed to be as constant as possible, with the obvious intention that vehicles move at a constant speed with as few changes in speed as possible. This reduces the undesirable effects of sudden or frequent braking or acceleration, thereby contributing to the safety of road users.

5 Conclusion

The FLC-based RVS system presented in this paper is a promising approach for optimizing traffic flow and enhancing road safety. Real-world traffic data is often imprecise or uncertain. Fuzzy logic can effectively incorporate this uncertainty into its calculations. A fuzzy controller can analyze these inputs in real-time and dynamically adjust the recommended speed based on the changing traffic conditions.

The RVS features the ability to robustly analyze traffic conditions based on various input parameters such as vehicle density and distance to the traffic congestion zone. This dynamic analysis enables the system to provide real-time insights into traffic congestion levels and potential hazards.

There are at least two FLC units in serial connection so that the output of FLC_1 unit is connected to an input of FLC_2 unit. The convexity property observed in the FLC_1 output indicates that as the number of vehicles increases, the traffic jam assessment value also increases, indicating the expected relationship between traffic congestion and traffic volume. This property increases the accuracy of the system in order to monitor traffic conditions and facilitates intervention.

FLC_2 outputs illustrate the system's ability to adjust recommended speeds based on the distance to the traffic jam road section. As the distance increases, the recommended speed also increases, promoting smoother traffic flow and reducing the likelihood of congestion buildup.

By minimizing sudden changes in speed through continuous and adaptive speed recommendations, the RVS contributes to enhancing road safety. Fewer instances of abrupt braking or acceleration reduce the risk of rear-end collisions and improve overall traffic fluidity, fostering a safer driving environment.

Ultimately, this analysis will serve as a basis for making informed decisions about further steps in the development of control systems relying on FLC.

Future work can include more interesting directions:

- Defining and developing the detailed architecture of such a system, from the point of view of hardware and software components. Cloud-based integration of the system with other public services, such as public transport planning, or environment protection services for residential, commercial and industrial areas.
- Mamdani type FLC can be replaced by Sugeno (TSK) type FLC. This would enable greater applicability of machine learning algorithms.
- The introduction of drones that would move along established routes near the road section, select "aggressive" drivers and transmit RVS with a special warning.

The application of machine learning algorithms based on artificial neural networks can be singled out as a special direction of future research.

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