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A Fuzzy Based Intelligent Traffic Light Control (ITLC) Method: An Implementation in Ankara City

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Abstract

The escalating global population and increased vehicle usage have worsened traffic congestion in metropolitan areas, a significant urban challenge. Addressing this, adaptive traffic light control methods, especially at intersections, are being developed to improve traffic flow and reduce waiting times. This study significantly contributes to this field by implementing Fuzzy Logic in intelligent traffic light systems, focusing on Ankara's Polatlı Refik Cesur intersection. Using the SUMO simulation platform and Python programming, it analyzed waiting times and queue lengths. The initial phase used queue length for each intersection arm as an input. Fuzzy logic rules then determined the output, prioritizing street or phase order for optimal flow. The study further proposed an Adaptive Neuro-Fuzzy Inference System (ANFIS)-based control plan. ANFIS merges neural network capabilities with fuzzy logic, using waiting time and queue length as inputs to regulate the green light duration. Compared to existing traffic systems, this model showed a substantial improvement. It achieved a 36.5% reduction in waiting times, underlining the efficiency of the Fuzzy Logic-based method. This approach not only enhances traffic management but also contributes significantly to the literature on intelligent traffic light control systems. By addressing key urban traffic issues, the study paves the way for future advancements in traffic management technologies. The findings highlight the potential of combining advanced computational methods, like ANFIS, with traditional traffic control techniques to optimize urban traffic flow, offering a blueprint for similar challenges in other metropolitan areas.

1. Introduction

Today's population continues to grow rapidly, and this increase brings significant challenges to the transportation sector. One of the primary challenges is the traffic congestion observed in large cities and densely populated areas. The increasing demand exceeds the capacity of roads and infrastructure, leading people to spend more time commuting to work, shopping, or traveling.Furthermore, vehicle exhaust emissions contribute to air pollution, releasing greenhouse gases into the atmosphere and causing climate change. Another issue resulting from traffic and vehicles is noise pollution High fuel consumption has adverse effects on both individual and national budgets Paragraphs following the first paragraph should begin with the paragraph indentation [1].

Building new roads to alleviate traffic congestion can be a traditional approach, but this method can create new environmental issues. In recent years, one of the approaches seen as a to alleviate traffic congestion is using intelligent traffic light control systems.

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These systems regulate the lights based on road density at each traffic intersection. Roads with lower traffic density result in less waiting time, while they can manage traffic more effectively in densely populated areas. This situation can improve traffic flow and reduce congestion [2].

Intelligent traffic light control systems can continuously monitor traffic data and adjust settings to optimize traffic flow. This approach provides environmental benefits such as reduced energy consumption and decreased air pollution. Therefore, using intelligent traffic control systems is a more appealing option to create a sustainable transportation system, as opposed to traditional infrastructure development. Traffic lights, especially at intersections, are considered one of the most effective ways of managing traffic. These lights not only ensure safe and efficient traffic flow but also reduce travel times, alleviate traffic congestion, and support the more effective use of road capacity [3]. Furthermore, they assist in enhancing safety and emergency management. All of these advantages demonstrate that adaptive intelligent traffic light control systems, sensitive to real-time traffic conditions, make a significant contribution to solving the problem of traffic congestion.

This study deployed intelligent controllers, including Fuzzy Logic and the Adaptive Neuro-Fuzzy Inference System (ANFIS), to manage traffic lights at a four-way intersection. The fuzzy logic controller decides which road to prioritize for the green light based on the vehicle queue length, while ANFIS processes waiting times and queue length data to determine the optimal duration for green traffic lights. Our research addresses a significant gap in the existing literature on traffic control systems. Despite the promise shown by intelligent traffic light control systems in optimizing traffic flow, the specific application and effectiveness of ANFIS, coupled with Fuzzy Logic controllers at a four-way intersection, still need to be explored. By addressing this gap, our study contributes valuable insights to enhance the comprehension of intelligent traffic control systems and their practical implementation.

The following sections of the paper will provide an in-depth exploration of ANFIS's utilization in the literature, the methodologies applied, and the detailed outcomes of its practical implementation.

2. ANFIS (Adaptive Neuro-Fuzzy Inference System)

ANFIS is a computational model that combines the fundamental principles of fuzzy logic and artificial neural networks to solve complex problems. This model is rooted in fuzzy logic, a mathematical framework designed to address uncertainty and non-precise situations, utilizing linguistic variables, fuzzy sets, and fuzzy rules to handle such uncertainties in the data. On the other hand, artificial neural networks are computational models inspired by the structure and functioning of the human brain. They consist of interconnected nodes, or neurons, which process information and transmit it through weighted connections. Artificial neural networks are known for their ability to learn from data and can be employed for various tasks, including pattern recognition, regression, and classification.

ANFIS effectively merges the strengths of both fuzzy logic and artificial neural networks. This approach, known as neuro-fuzzy systems, provides a flexible and robust solution, particularly in complex domains where data is incomplete or imprecise. In fields such as control systems, decision support, and modeling real-world problems, these neuro-fuzzy systems are practical tools to address complex, uncertain, and non-precise scenarios [4]. In Figure 1, the general structure of our ANFIS model is illustrated.

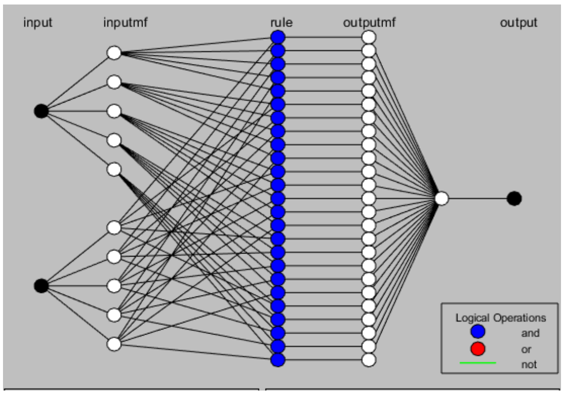

Figure 1. ANFIS model structure in Matlab

The terms "inputmf (input membership functions)" and "outputmf (output membership functions)" indicate the type of fuzzy logic membership functions associated with the input and output variables of this model.

3. Literature Review

Various studies have proposed different approaches and methods to enhance traffic light control. Among these approaches, one prominent method is the Adaptive Neuro-Fuzzy Inference System (ANFIS). ANFIS employs a hybrid training method that can automatically generate fuzzy rules based on the dataset [5].

Araghi et al. developed a cuckoo search optimization algorithm to optimize the parameters of intelligent controllers using ANFIS. This study investigates how ANFIS can be employed in traffic light control and assesses the effectiveness of ANFIS-based traffic light controllers [6].

Walukov et al. determined the green light duration for a four-way isolated intersection using ANFIS. Traffic volume and waiting time were utilized to determine the green light duration as the output. This study demonstrates how traffic light control can be optimized using ANFIS [4].

Araghi et al. compared interval type 1 ANFIS, interval type 2 ANFIS, fixed fuzzy logic, and three different fixed-timing fuzzy logic methods for traffic light control. The comparisons revealed that fuzzy controllers outperformed traditional controllers. This study developed a distributed control system for a network comprising nine intersections. Each intersection had its controller and considered traffic density in neighboring intersections when determining signal durations for traffic phases. This approach contributes to making traffic light control more efficient and effective. It underscores the significance of fuzzy logic-based methods in traffic light control [7].

Andayani et al. applied the Adaptive Neuro-Fuzzy Inference System (ANFIS) method by using traffic density and road width data to determine the traffic light duration. This study was conducted to optimize traffic light control and adopt an approach sensitive to traffic density. ANFIS processed the data on traffic density and road width to target the most efficient determination of green light durations [8].

Abiodun et al. have adopted the Adaptive Neuro-Fuzzy Inference System (ANFIS) method with the sole aim of controlling traffic lights based on road density. This study was conducted to regulate traffic flow and effectively manage traffic density. Road density data were processed by ANFIS and used to determine the durations of traffic light signals [9]. In another study, vehicle density and road width data were the basis for determining signal durations. The manually collected data were processed using the Fuzzy Logic method, leading to the optimization of signal durations. This study was carried out in a simulation environment, demonstrating the effectiveness of the technique [10].

George et al. employed the Internet of Things (IoT) and the Adaptive Neuro-Fuzzy Inference System (ANFIS) to enhance traffic conditions. In this study, an ANFIS traffic light controller was developed in the MATLAB SIMULINK environment, utilizing inputs such as waiting time and vehicle density. Cameras were employed to detect traffic density, and the captured images were sent to the cloud. Subsequently, these images were analyzed on a server using the ANFIS controller to ascertain the suitable signal durations [3]. Azura et al. have proposed a fuzzy logic-based traffic controller for multi-lane isolated signalized intersections. This controller, developed using MATLAB, relies on the current green light status, vehicle waiting times, traffic density, and traffic density in other intersections. Additionally, in this study, a traffic model based on queue theory and the First-In-First-Out (FIFO) principles has been developed [11].

Utomo et al. have proposed ANFIS as a controller for two adjacent intersections in Djuanda-Bandung. This system can adjust real-time traffic light phase durations for both intersections based on traffic conditions. Vehicle queue length and changes in these queues were used as inputs for ANFIS during the adjustment process. ANFIS, as a result, generates an output value such as street urgency. Through MATLAB simulations, it was revealed that this ANFIS-based control system outperformed the traditional fixed-timing traffic control method [12].

Awoyera et al. have proposed an Intelligent Traffic Control System (ITCS) based on the Adaptive Neuro-Fuzzy Inference System (ANFIS) using real-time traffic data obtained from different traffic lanes. The ANFIS-based ITCS can learn from historical traffic data and consider traffic data from side lanes to predict future traffic flow on the main road. Simulations confirmed that this intelligent traffic control system based on ANFIS provided a lower average delay for different vehicle queue lengths and waiting times at a four-lane road intersection [13].

Araghi et al. offer an optimal approach for traffic signal controllers designed by the Adaptive Neuro-Fuzzy Inference System (ANFIS). This controller aims to adjust green times at a single intersection to improve traffic flow and reduce congestion. The ANFIS controller has the learning capability to determine suitable green times for each traffic phase. During this learning process, the Cuckoo Search (CS) algorithm has been utilized for parameter tuning. The performance of the proposed method has been compared to Fuzzy Logic Controller (FLC) and fixed-timing traffic control methods. The results demonstrate that the ANFIS controller outperforms the other comparative controllers, showcasing its effectiveness [14].

Zeynal et al. have presented an innovative approach to control traffic flow in congested areas efficiently. They introduced an innovative input-selective adaptive network-based fuzzy inference system (ANFIS) approach, enhancing the ANFIS prediction system. The proposed model has been tested at an intersection in Mashhad, Iran [15].

Mittal and Cavla highlight that traffic congestion in urban areas is one of the primary issues that can be addressed through infrastructure improvement and the construction of one-way roads. One-way roads can increase vehicle speed and reduce travel times. Since congested roads can make the control of isolated intersections inefficient, coordinated traffic intersections on the roads are beneficial. In this article, signal coordination techniques based on the distance between two intersections are proposed. This ANFIS-based system is compared with linear and decision tree regression methods, demonstrating its effectiveness. They used average delay time as the comparison parameter If necessary, subheadings can be added under the main heading [16].

4. Methodology and Implementation

The current state of the Polatlı Refik Cesur intersection in Ankara province, which experiences high traffic density, and the outcomes of applying the proposed models have been examined. The general layout of the intersection is illustrated in Figure 2. It is a four-way intersection with five phases, one of which is the pedestrian phase, comprising ten lanes. The numbers in Figure 2 represent directions. The intersection allows for straight, right, and left turns. There are eight traffic signals, and different traffic signals control right turns.

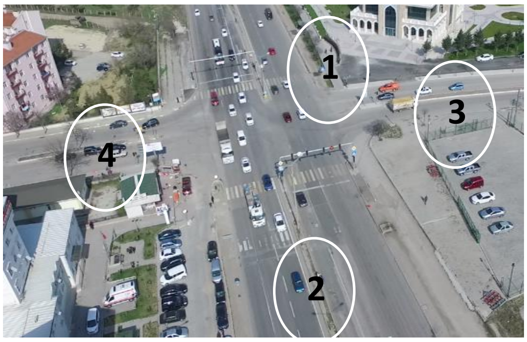

Figure 2. Polatlı Refik Cesur intersection.

The data for the Polatlı Refik Cesur intersection was obtained by the Gazi University Urban Transportation Technologies Accessibility Application and Research Center (KUTEM). This dataset includes the hourly counts of vehicles, vehicle types, weather conditions, vehicle routes, current phase information, and the existing light plan from 08:00 to 16:00. There are five types of vehicles in traffic: cars, buses, trailers, medium-duty commercial vehicles (MDCV), and trucks. An example of the dataset for cars is shown in Table 1. The table provides the counts of cars entering the intersection at one-hour intervals, heading in different directions.

In this study, the traffic light control system of an isolated four-lane traffic intersection has been examined using fuzzy logic and ANFIS-based intelligent control mechanisms. This mechanism operates under the assumption that the arrival times of vehicles follow a Poisson distribution without prior knowledge.

Table 1. Traffic flow example at Polatlı Refik Cesur intersection

Vehicle type	Time	Street 1 (Eskişehir-Ankara)			Street 2 (Ankara-Eskişehir)			Street 3 (Polatlı- Huzur evi)			Street 4 (Huzur evi- Polatlı)		
		1 - 2	**1 – 3**	**1 - 4**	**2 -1**	**2 - 3**	**2 - 4**	**3 – 1**	**3 - 2**	**3 – 4**	**4 – 1**	**4 - 2**	**4 – 3**
CAR	08-09	400	42	25	437	132	22	25	205	95	21	55	105
	09-10	443	38	14	401	126	20	20	190	80	20	51	95
	10-11	563	43	11	380	121	18	16	169	75	27	54	80
	11-12	505	40	13	466	116	16	15	171	60	25	50	75
	12-13	606	38	17	529	109	15	18	168	56	23	45	69
	13-14	599	29	16	571	95	25	6	251	61	42	29	146
	14-15	675	32	17	630	209	29	23	242	125	25	28	85
	15-16	825	26	15	697	215	48	13	265	102	35	24	91

This article presents a fuzzy logic-based intelligent control mechanism for managing traffic lights at the intersection. The primary goal is to enhance traffic flow and increase intersection capacity to reduce waiting times. Initially, the next phase allowed in traffic is determined. Subsequently, an integrated system model is created that extends the green light duration adaptively, considering vehicle density and waiting times. The model structure is depicted in Figure 3.

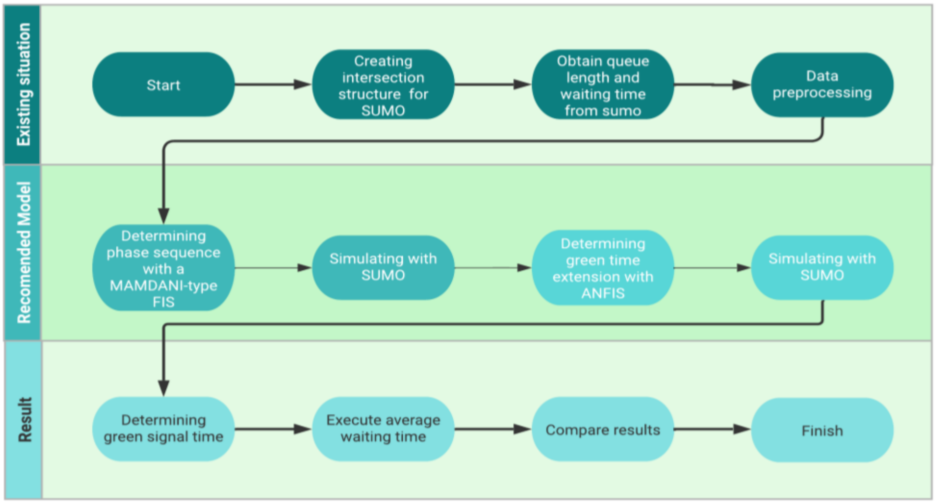

Figure 3. Traffic controller model

4.1. SUMO (Simulation of Urban Mobility)

The intersection was visualized in the SUMO (Simulation of Urban Mobility) simulator based on accurate data, and real-time data on the number of vehicles in the queue and waiting times were collected using Python programming. The SUMO simulation platform was chosen due to its open-source nature and its ability to simulate individual behaviors of vehicles in traffic, as well as handle continuous events. Additionally, SUMO is a powerful tool for dynamic time simulations [17].

These typical four-lane intersections operate based on the M/M/1 queuing theory principle. According to this theory, vehicles enter the queue to receive service, following the first-come, first-served principle. However, in this study, an intelligent control system has been used instead of fixed-time traffic light control plans.

The traffic flow of the existing intersection was visualized in the SUMO simulation platform. Figure 4 provides a visual representation of the Polatlı Refik Cesur Intersection in the SUMO simulation environment. Real-time data on the number of vehicles in the queue and waiting times were extracted from SUMO and recorded in Excel.

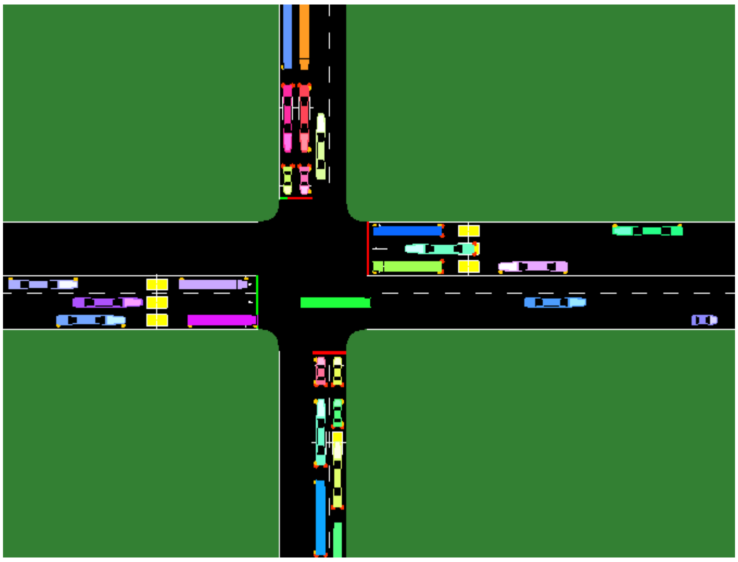

Figure 4. SUMO intersection structure image

4.2. Next Phase Modul

At this stage, a system has been developed that automates the control of the traffic intersection using fuzzy logic. Rule-based Mamdani-type fuzzy modeling technique is used to model the system [18]. At this stage, the system parameters for each street, such as vehicle density and the sequence of phases for street selection, are defined. The membership functions of these parameters are determined by fuzzy logic. Using data extracted from SUMO, the queue length (very short, short, long, very long, extremely long) was defined for each street. The street with the longest queue is the one to receive the green light in the next phase. As a result of this process, the following traffic phase has been determined.

Firstly, the street to which the green light will be given was determined by the Mamdani fuzzy logic system, as shown in Figure 5.The results obtained should be included in this section and supported by figures and tables if necessary.

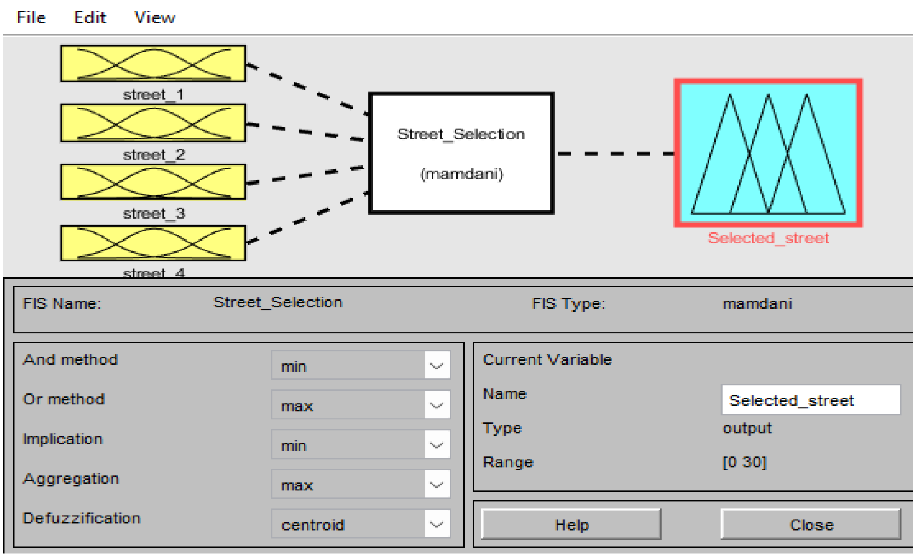

Figure 5. A Mamdani-type fuzzy logic model for street selection

In the fuzzy logic modeling process, after determining the input and output parameters, the decision is made on the number of linguistic variables for each. Then, the type of membership function is selected. In the first section of this study, queue length is used as the input parameter, and street selection is used as the output parameter. Gaussian membership functions were preferred. The roads at the intersection are named street_1, Street_2, Street_3, and Street_4, respectively, and for input parameters, the queue length of each road is named "very short," "short," "long," "very long," "extremely long." A different Gaussian membership function is defined for each road. The membership function for Street_1 is shown in Figure 5. The output functions for street selection are determined as "street 1," "street 2," "street 3," and "street 4." The designed input and output membership functions are shown in Figure 6.

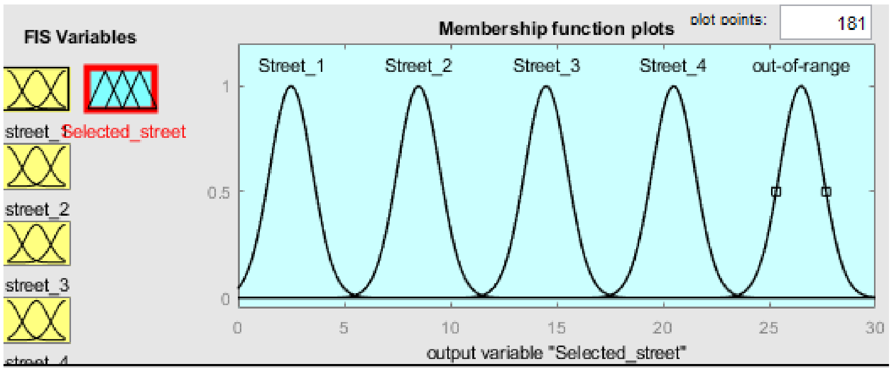

Figure 6. The output membership functions for the selected street

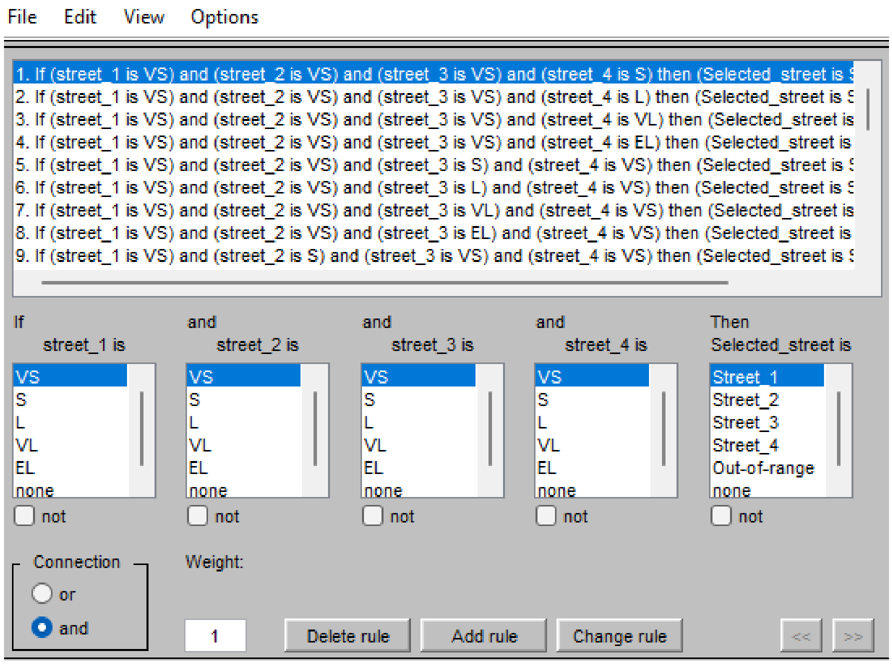

Figure 7. The rules created for street selection

In this study, specific rules have been created to provide an intelligent control mechanism by the system. These rules involve the selection of a street based on the traffic density level of each road. For example, according to the second rule, if the queues of Street_1, Street_2, and Street_3 are "Very Short," and the queue of Street_4 is "Long," then Street_4 is preferred.

4.3. Green Time Extension Module

During this stage, the duration of the green light for the initially determined traffic phase is calculated to determine how much it should be extended. This duration can be adjusted based on traffic density and waiting times. ANFIS (Adaptive Neuro-Fuzzy Inference System) controls traffic lights by observing vehicle waiting times and queue lengths. As a result, the traffic signal timing can be adjusted based on traffic density and the number of vehicles on each street, making traffic flow more smoothly [19].

This system determines the traffic signal phase sequences using Fuzzy Logic and directs traffic flow by adjusting the green light duration for each traffic phase using ANFIS technology. This approach ensures a more efficient traffic flow. The reason for using the ANFIS model is its ability to adjust this duration based on traffic conditions dynamically.

The process of assigning green light durations to phases is modeled by Fuzzy Logic or Fuzzy Inference System (FIS). In fuzzy logic, it looks at the degree of conformity to the rule's antecedent. The obtained degree of conformity is then subtracted from the consequences of each rule. All the results are combined to obtain the overall result.

ANFIS traffic signal controller uses a Sugeno-type fuzzy logic system. In the consequent part of the rules, a first-order Sugeno-Type FIS employs a linear system to model the output membership functions. This system operates based on specific rules. FIS constructs the output membership function based on the following rules.

If input_1= x and input_2=y.Then, the output_z is calculated as output_z = ax + by + c. It computes an output value using a linear combination of two inputs. The terms "a" and "b" represent the multipliers of the input values, while "c" is a constant term. The parameters a, b, and c are related to traffic light control and are used to determine the green light duration. These parameters are used to calculate the outcomes of a specific traffic signal control strategy or algorithm. "a" and "b" are the weights of the inputs used to determine the traffic light duration (e.g., queue length and waiting time). "a" represents the impact of queue length on the green light duration. A significant "a" value implies that queue length has a more significant influence on the green duration. "b" represents the impact of waiting time on the green light duration. A significant "b" value implies that waiting time has a more significant influence on the green duration. "c" represents the initial value of the traffic light, meaning it represents the initial duration of the green light. For example, a value like c = 2.4 would initiate the green light with a duration of 2.4 time units [13].

To achieve the best simulation results, we use optimal weights of a = b = 0.026 and a fixed value of c = 1. This rule employs a linear model to produce an output based on inputs and combines these outputs to obtain the overall result. As a result, the extension durations of green phases can be adjusted based on a specific logic, and it can be used to optimize traffic flow.

Input_1 (x) = Queue Length, Qt (0 - 60 vehicle)

Input_2 (y) = Waiting Time, Wt (0 - 80 second)

Output_z = Green Extension Time, Et (0 - 6 second).

Hence, the Green Light Extension Output, Et, is expressed as Et = a[Wt] + b[Qt] + c.

In the Data Preprocessing step, the available data has been analyzed, and meaningful cleaning, imputation of missing values, and correction of outliers have been carried out.

The data has been divided into two sections using MATLAB software: training data (70%) and test data (30%). The training data includes the data on which the model was trained, while the test data was used to evaluate the performance of the trained model. The ANFIS model was trained on the training set and then evaluated on the test data. The proposed Smart Traffic Control System network design is shown in Figure 8.

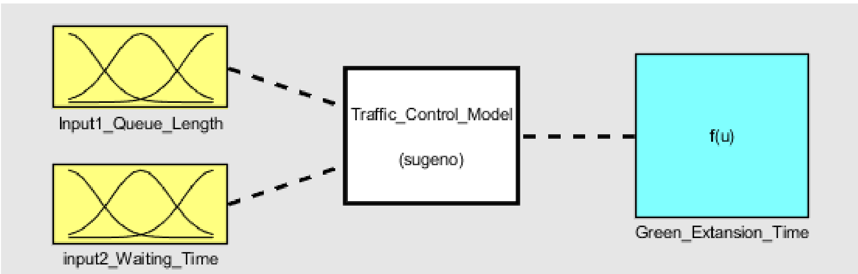

Figure 8. Fuzzy logic control for intelligent traffic

Fuzzy membership functions for all the necessary input and output variables for traffic light control have been defined separately. These inputs are queue length (Qt) and waiting time (Wt). The output variable is the extension time of the green light (Et). Based on the data, the range of input membership functions has been defined as follows: According to the data obtained from SUMO, the queue length varies between 0 to 60 vehicles, and the waiting time ranges from 0 to 80 seconds. The input membership functions are graphically represented in Figure 9 and Figure 10. Five different labels have been defined: very short (VS), short (S), long (L), very long (VL), and extremely long (EL).

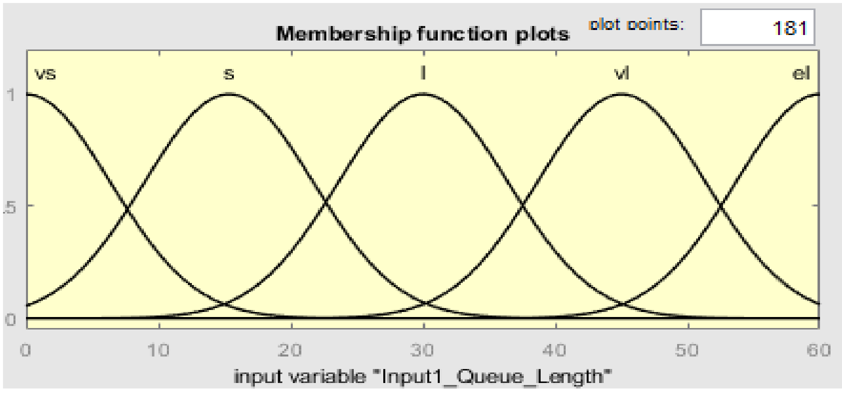

Figure 9. Vehicle queue length 0-60 vehicles.

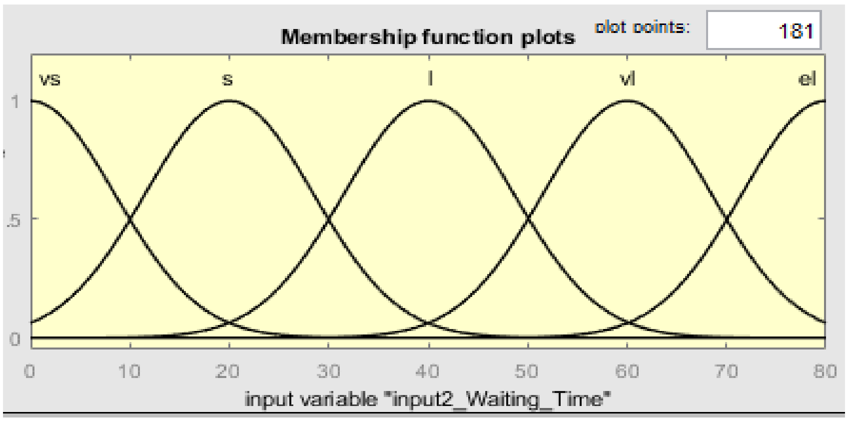

Figure 10. Vehicle waiting time 0-80 seconds

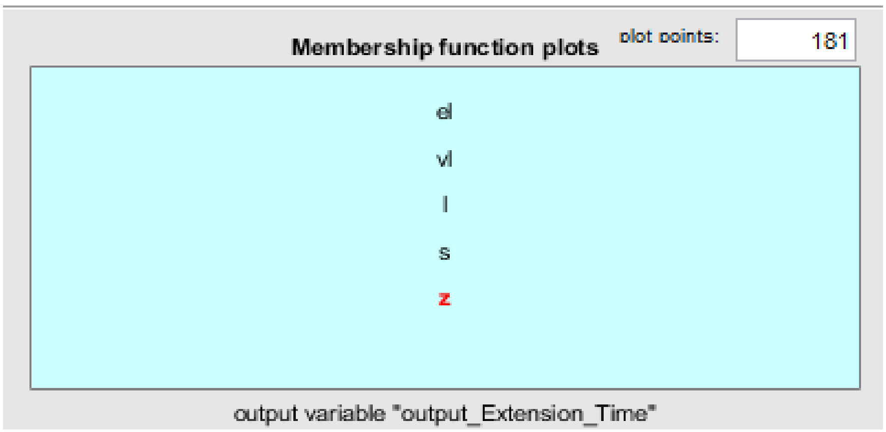

Figure 11. Green extension time 0-6 seconds

The range of output membership functions, on the other hand, varies between 0 and 6 seconds, and these functions are presented in Figure 11. Afterward, fuzzy rules were written using IF-THEN statements. The IF part represents the condition to be met, and the THEN part indicates the action to be taken when the condition is met. The rules are shown in Figure 12.

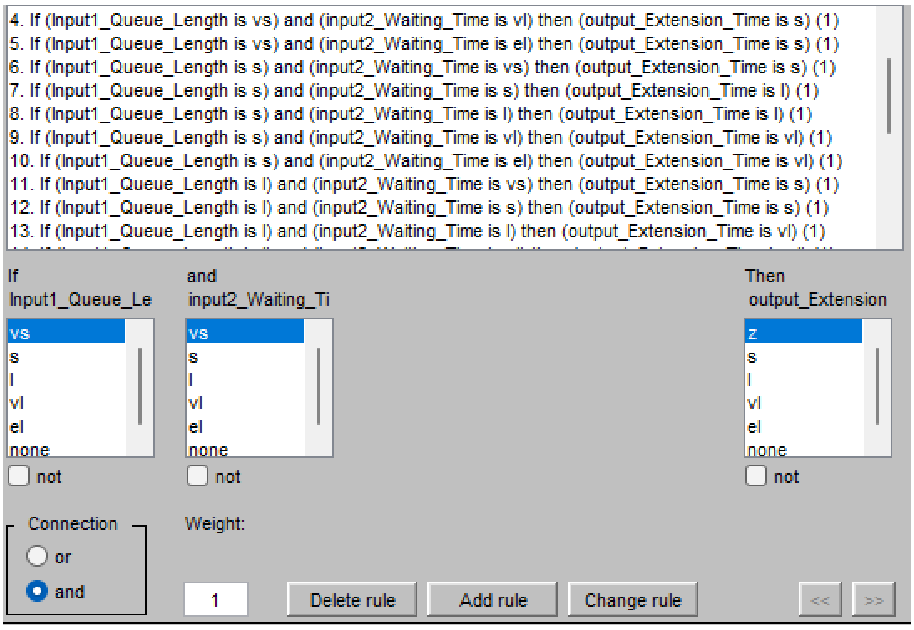

Figure 12. Fuzzy rule editor

5. RESULTS

In this study, firstly, the Polatlı Refik Cesur intersection was simulated using the SUMO simulation platform. Then, using the PYTHON programming language, the waiting times and queue lengths of vehicles obtained from this simulation platform were extracted. In the initial stage, using these data, it was determined in which phase the green light should be on using a Mamdani-type Fuzzy Logic model, as shown in Figure 6. For instance, if street_1, street_2, and street_3 have short queues, while street_4 has a long queue, the phase containing street_4 is determined as the new phase where the green light needs to be activated. After determining the phase sequence, it was decided how the green light duration should be adjusted using an ANFIS model that considers the queue length and waiting times on the street. The output of the ANFIS traffic controller is shown in Figure 13. This method presents an approach that combines simulation and fuzzy logic modeling to address complex traffic control problems and is used to adapt green light durations to make traffic flow more efficient.

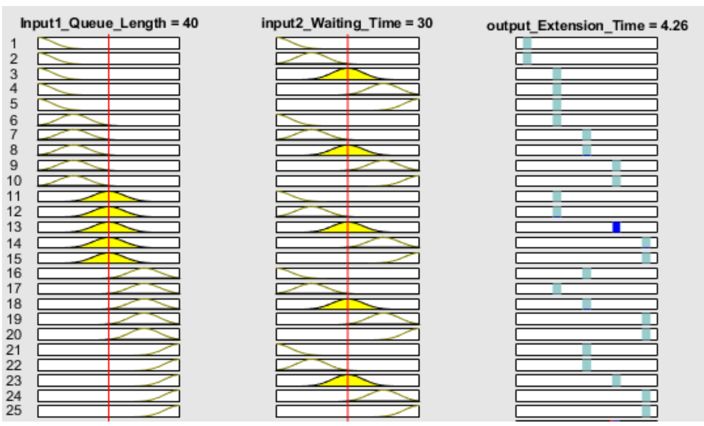

Figure 13. Fuzzy Rules ve Green Time Extension

When the queue length for any vehicle is considered 40 vehicles and the waiting time is 30 seconds, the ANFIS-based model calculates the green light duration as 4.26 seconds. Figure 14 shows a surface plot of one output function and two input variables. This graph demonstrates that as the queue length and waiting time of vehicles increase, the green light duration also increases. This duration can go up to a maximum of 6 seconds. The ANFIS controller adjusts the green light duration for different traffic densities and waiting times. Table 2 provides a detailed breakdown of the increases in green light duration for different waiting times and queue length scenarios. These results emphasize the effectiveness of ANFIS-based control in managing traffic flow.

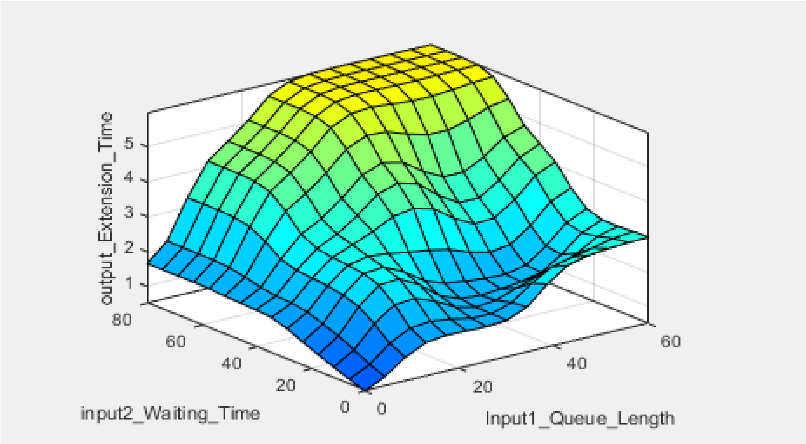

Figure 14. Surface views for ANFIS outputs

As the queue length and waiting time of vehicles increase, the green light extension time gradually increases. It has reached a maximum of 6 seconds. As shown in Table 3, the ANFIS controller effectively assigns green light extension time when different traffic volumes and waiting times are provided.

Table 2. Performance of the system

Queue Length	Waiting Time	Extension Time
5	10	1,17
10	10	1,75
15	15	2,56
20	20	2,87
25	25	2,97
30	25	3,32

The average error of the test set was calculated as 0.92648. The ANFIS method was used to optimize the green light durations. Figure 15 displays the ANFIS model created in MATLAB. This model has been successfully employed in traffic signal control. The blue dots represent the actual rules, while the red ones represent the rules of our model. The optimization model is selected as "hybrid". This means that a combination of genetic algorithm and gradient-based methods is used during the training of the ANFIS model. This can help the ANFIS model perform better. The epoch value is set to 3, indicating that the ANFIS model is trained for a maximum of 3 epochs. Each epoch represents the updating of the model on the training data and the learning process. Using more epochs means the model is trained further, but excessive epochs can lead to overfitting issues [20]. Therefore, an epoch value of 3 has been chosen.

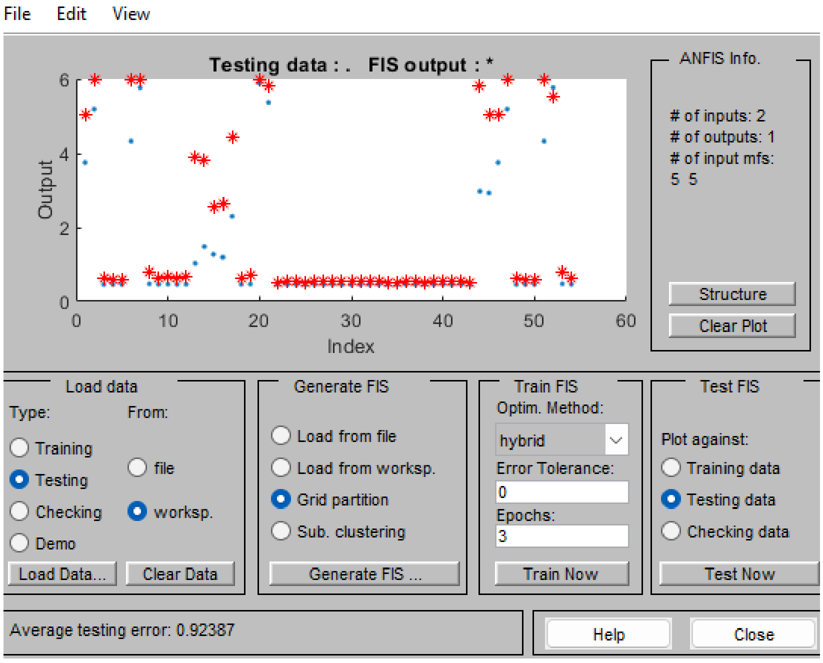

Figure 15. The simulation of ANFIS

5.1. Simulation Results

The proposed new Intelligent Traffic Control model has been integrated with the SUMO (Simulation of Urban Mobility) simulation platform, and its impact on per-vehicle waiting times has been thoroughly investigated. The research results present the observed improvements in waiting times for each street in Table 2.

Table 3. The improvement achieved in waiting time

Street Name	The waiting time per vehicle while fixed-time (sec/vehicle)	The waiting time per vehicle after the proposed model (sec/vehicle)	Improvement in waiting time (sec/vehicle)	Improvement in waiting time (%)
Street 1	80.45	38	42.45	**53**
Street 2	76.17	40.20	35.97	**47.2**
Street 3	58.14	50.21	7.93	**13.6**
Street 4	62.41	42.32	20.09	**32.2**

As seen in the table, there is a 36.5% reduction in the average waiting time at the intersection. For Street 1, which has the highest waiting time, the fixed-time traffic light plan results in a delay of 80.45 seconds per vehicle, while with our proposed model, this time is reduced to 38 seconds. The improvement in waiting time is 42.45 seconds. Proportionally, an approximate 53% improvement has been achieved.

Figure 16 provides a comparison between the proposed fuzzy logic and ANFIS-based new Intelligent Traffic Light Control (ITLC) system and the traditional fixed-time traffic light control (FTLC) system based on instantaneous waiting time data during a 500-second simulation period of vehicles following a Poisson distribution. As can be seen from the figure, the newly proposed system has significantly reduced waiting times.

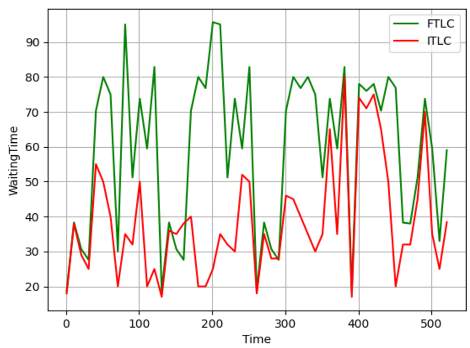

Figure 16. Simulation results for waiting time

Figure 17 presents a graph showing the change in the number of vehicles waiting in the queue over time, as recorded instantaneously by SUMO (Simulation of Urban Mobility). The proposed system tends to reduce the number of vehicles in the queue. This situation supports the observed decrease in waiting times.

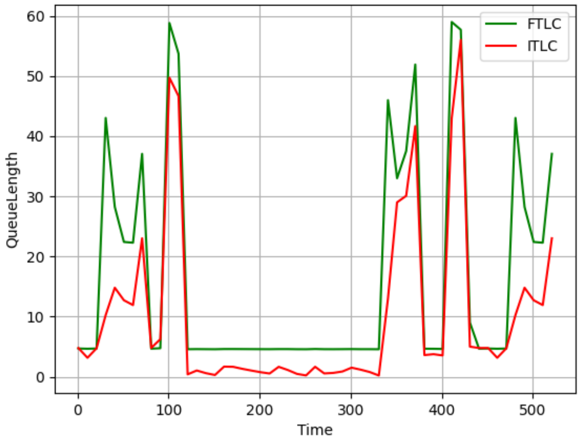

Figure 17. Simulation results for queue length

According to the data presented in Figures 16 and 17, when the queue length is low, the proposed model outperforms the fixed-time traffic light control model. However, when the queue length increases, it is observed that our model achieves relatively better results. One of the primary reasons for the improved performance of the proposed model is the more efficient utilization of intersection capacity and the faster clearance of incoming vehicles from the intersection.

6. Conclusion

This study focuses on the challenges of real-time traffic control at an isolated intersection under uncertain traffic conditions. The developed system presents an effective method for monitoring and regulating traffic flow by integrating a Mamdani-type fuzzy logic model and ANFIS-based systems. The proposed model demonstrates a performance trend of reducing waiting times by minimizing queue lengths facilitating faster intersection clearance for entering vehicles. As a result, the intersection is utilized more efficiently, achieving reduced waiting times and queue lengths compared to the fixed-time traffic light control method.

As part of future research, the potential applications of this system involve more comprehensive studies incorporating multiple intersections and considering the traffic status of adjacent roads. Such an integrated system could extend beyond a single road, potentially optimizing traffic management in broader geographical areas. In conclusion, this study provides a solution to the complexities of traffic control and enhances traffic flow by effectively combining fuzzy logic and ANFIS technologies. To enhance the practical impact of our findings, we propose recommendations on how this system can proactively prevent congestion in real-world scenarios. Our findings, based on original datasets, emphasize the potential of the proposed system to play an influential role in traffic management and offer unprecedented solutions. In this context, the results of our study provide a valuable foundation for researchers and decision-makers aiming to understand the practical impact of the developed method and improve future traffic management strategies.

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Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics

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