The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2024

Volume 31, Pages 31-41

ICATI 2024: International Conference on Advances in Technology and Innovation

Intelligent Traffic Lights Control System: Riyadh City

Amjaad Alfaifi
King Saud University

Fairouz Tchier
King Saud University

Abstract: Traffic congestion is one of the main problems facing Riyadh city's growth, which results in significant environmental pollution and makes transportation difficult. These factors not only generate material losses but also make daily living difficult for people. The principal reasons of traffic congestion in Riyadh include, but are not limited to, the rapid growth of the population. By 2030, the Kingdom of Saudi Arabia aims to have a population of 50-60 million, which will make traffic congestion worse if preventive measures are not taken. The development of an intelligent traffic lights control system is one strategy to address traffic issues. The purpose of traffic lights is to efficiently control vehicle traffic at intersections. These traffic signals typically operate in a preset order based on a fixed cycle period. Due to this design, vehicles on one side of the road must wait even while there are no automobiles on the other, making them intrinsically unable to effectively regulate traffic flow during atypical conditions. As a result, it becomes necessary to simulate traffic control algorithms in order to reduce the amount of stops, vehicle delays, etc. There is a chance to create a system that will meet these needs with fuzzy logic. We use fuzzy logic toolbox in MATLAB to design the intelligent traffic lights control system for an isolated traffic junction.

Keywords: Traffic lights controller, Fuzzy logic, Extension time

Introduction

Fuzzy mathematics can be considered as an extension of classical logical systems. Fuzzy logic offers an effective conceptual framework for addressing the challenge of knowledge representation in an uncertain and imprecise context as it mimics human reasoning, this conceptual leap boosts mathematics' usefulness and expands its applications (Ande, 1996).

Around the world, one of the biggest issues with modern cities is traffic congestion. Traffic congestion is a major cause of many difficulties and obstacles. Traveling between locations becomes more challenging due to the abundance of cars in crowded cities. People waste time, miss chances, and get disappointed as a result of these traffic issues. Companies are directly impacted by overcrowding. As a result, employee productivity declines, opportunities are wasted, deliveries are delayed, and costs continue to climb (Chabchoub et al., 2021). Therefore, one of the most critical issues that must be fixed in order to boost any nation's economy is traffic congestion. In Riyadh city, the principal reasons of traffic congestion include, but are not limited to the rapid growth of the population. By 2030, the Kingdom of Saudi Arabia aims to have a population of 50 - 60 million, with Riyadh's maximum population of 25 million (SABQ, 2022), which will make traffic congestion worse if preventive measures are not taken.

The development of an intelligent traffic lights control system is one strategy to address traffic issues. Conventional methods for traffic light control based precise models failed to deal efficiently with the complex and varying traffic situations. They were modeled based on the fixed cycle time to change the signal without any analysis of traffic situation. Due to this design, vehicles on one side of the road must wait even while there are no automobiles on the other, making them intrinsically unable to effectively regulate traffic flow during atypical conditions (Alam et al., 2013). Therefore, even with the advancement of technology, traffic police officers are still assigned to areas of congestion in order to boost flow rates by using their cognitive abilities. Due to its ability to translate traffic police officers' methods of managing traffic lights into mathematical models and algorithms, fuzzy logic based traffic light control algorithms are essential for improving traffic flow management in urban areas and enabling drivers to engage with their environment in a cooperative and intelligent manner. In light of these benefits, our goal is to use fuzzy logic technology to design an intelligent traffic light control system for isolated intersections that can adapt to the traffic demands of Riyadh city. Numerous scholars have tried to apply fuzzy logic to traffic control in the past. Pappis and Mamdani made an early attempt to use fuzzy logic to traffic control, showing that it could be applied to specific traffic intersections (Alam et al., 2013; Pappis et al., 1977).

Algorithms of Traffic Light Controller

The following are two common strategies employed for controlling traffic lights (Omina, 2015; Salehi et al., 2014; United States Department of Transportation, 2021):

1. Fixed-time signal control algorithm:

This kind of control does not analyze the traffic condition; instead, it changes the traffic lights based on a predetermined cycle period. Fixed-time control offers a number of benefits. Since the start and finish of green light are predictable, it can be utilized, for instance, to offer effective coordination with nearby fixed-timed signals. Its operation is also resistant to issues related to detector failure because it does not require detectors. Lastly, setting it up and keeping it running just takes a minimal bit of training. On the other hand, fixed-timed control is ineffective at isolated intersections where traffic arrivals are random and is unable to account for unplanned fluctuations in traffic flows.

2. Real-time signal control algorithm:

This control integrates proximity sensors, which have the ability to trigger a change in the cycle time or the lights, with a predefined cycle time. Proximity sensors will cause a change in light when cars are present on a roadway with less traffic, which may not require a regular cycle of green lights. Real-time signal control algorithm is more flexible to real-world traffic conditions because it utilizes data acquired by detectors. Based on a set of rules and the state of the traffic, a decision is taken about signal control.

We will concentrate on the use of fuzzy logic controllers in traffic light systems that use sensors that count vehicles, as opposed to proximity sensors, which simply detect the presence of vehicles. The number of cars waiting in each direction determines how the traffic lights should adjust their signaling patterns. This enables a better evaluation of shifting traffic patterns by giving the controller information about traffic concentrations in the lanes.

Fuzzy Logic Control System

Here, we may demonstrate a fundamental setup for fuzzy logic control. Figure 1 illustrates how the fuzzy logic control operations can be broken down into three main stages (Javatpoint, n.d.; Priy, 2023):

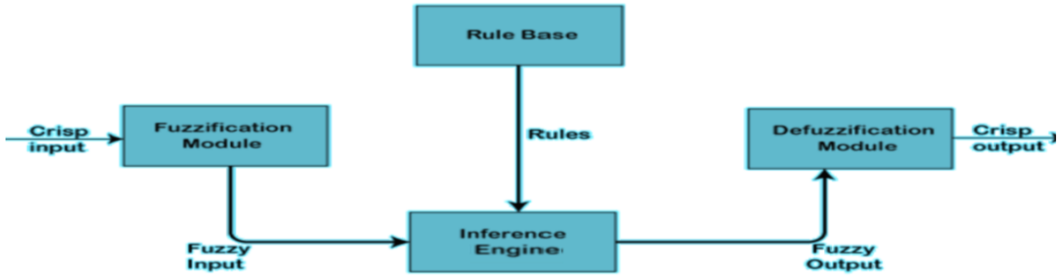

Figure 1. Process of a fuzzy logic control system

Fuzzification is a component for transforming the system inputs, i.e., it translates accurate crisp input values into linguistic variables. The crisp numbers are those exact inputs measured by sensors and then fuzzification passed them into the control systems for further processing.

Fuzzy Inference Engine is the key component of the fuzzy system. To accomplish the primary goal of issue solving, it uses fuzzy or approximate inference to mimic human thought processes and decision-making styles. It utilizes the "IF-THEN" rules as a basis to determine the optimal course of action for any given circumstance and infers the fuzzy outcome from fuzzified inputs. The fuzzy IF-THEN rules are the rule base that includes all relevant input-output combinations created by the user to suggest a mathematical link between them. The rule connects an output or conclusion to a condition given by fuzzy sets and linguistic variables. The "IF" section is mostly used to record knowledge using elastic conditions, and the "THEN" section can be used to deliver the conclusion or output in the form of a linguistic variable. Based on human knowledge or experience, the legislation to establish a set of fuzzy IF-THEN rules depends on each specific application.

Defuzzification is the final phase in the fuzzy logic controller process, which is simply the process of turning the conclusions produced by the fuzzy inference engine into crisp values. To make the conclusion or fuzzy output applicable to real-world applications, this procedure is necessary. A variety of defuzzification techniques exist, and the most appropriate one is employed in conjunction with a particular expert system to minimize error.

Fuzzy Logic Traffic Light Controller

For the isolated 4-lane traffic intersection (north, south, east, and west), a fuzzy logic controller will be constructed using fuzzy logic toolbox in MATLAB. The amount of traffic on the arrival side (Arrival), the amount of traffic on the queuing side (Queue) and the range of visibility during driving (visibility) are the traffic lights controller fuzzy input variables. In the event when both the north and south are green, they are regarded as the arrival side and the west and east as the queuing side, and vice versa. The length of time required for the arrival side green light (Extension) would be the fuzzy output variable, as seen in Figure 2. Therefore, fuzzy rules can be created based on the current traffic conditions to determine whether or not the fuzzy controller's output will extend the present green light time.

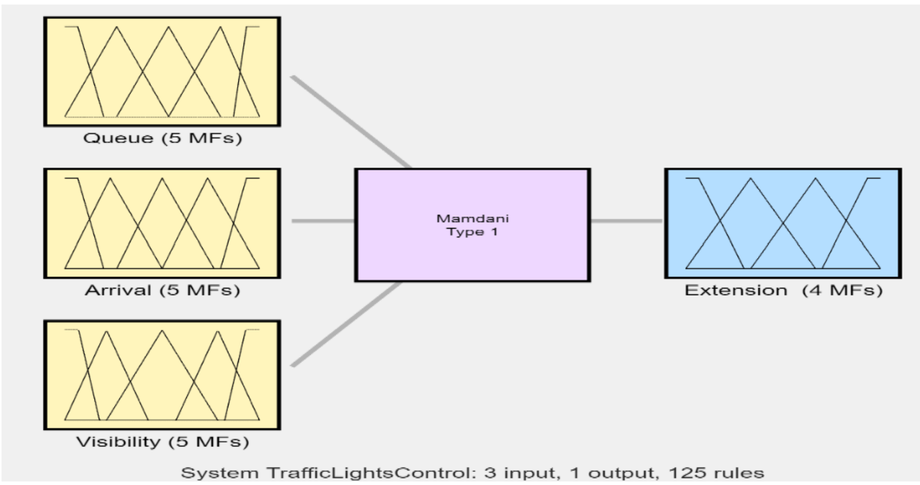

Figure 2. Fuzzy inference system

Membership Functions

Queue (Input)

The membership function of the linguistic variables of Queue is presented in Table 1. It can be observed that there are five linguistic variables: very short, short, medium, long, and very long. As seen in Figure 3, the y-axis of the graphical representation of the membership functions of the linguistic variables of Queue is the degree of its membership and the x-axis is the number of Queue of vehicles. The range of this input variable is selected from 0 to 15 vehicles.

Table 1. Queue membership function description

Fuzzy Set	Membership Function Type	Parameters
Very Short	Trapezoidal	[-1 0 1 3]
Short	Triangular	[0 4 8]
Medium	Triangular	[4 8 12]
Long	Triangular	[8 12 15]
Very Long	Trapezoidal	[13 14 15 20]

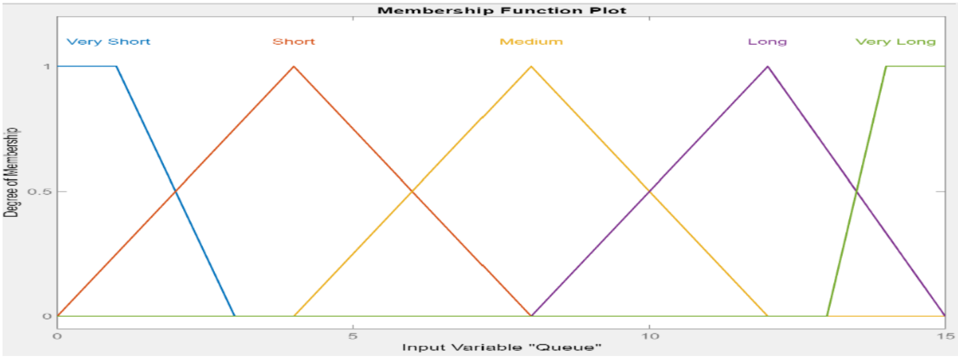

Figure 3. Queue membership function plot

Arrival (Input)

The linguistic variables of arrival input variable are very few, few, average, many and too many. Its values range from 0 to 30 vehicles, as seen in Figure 4.

Table 2. Arrival membership function description

Fuzzy Set	Membership Function Type	Parameters
Very Few	Trapezoidal	[-1 0 2 6]
Few	Triangular	[0 7 15]
Average	Triangular	[8 15 23]
Many	Triangular	[15 22 30]
Too Many	Trapezoidal	[24 28 30 35]

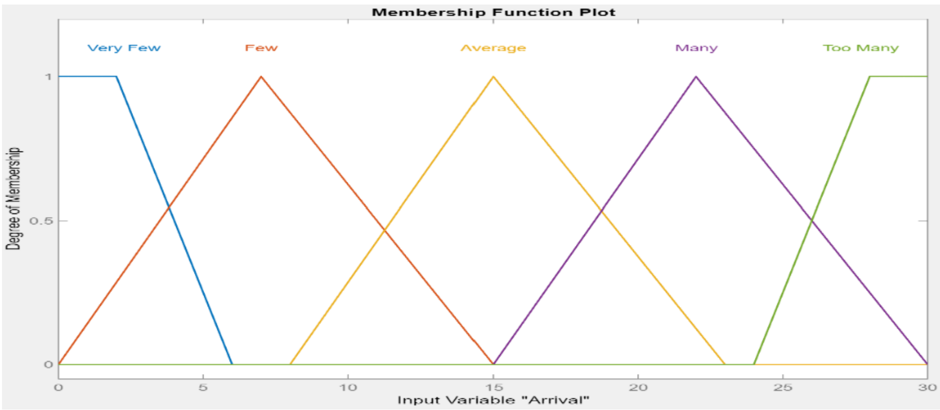

Figure 4. Arrival membership function plot

Visibility (Input)

Due to Saudi Arabia's arid geographical location, dust storm is meteorological phenomenon common in Riyadh, and it peak in the summertime in particular. It goes without saying that it is risky to drive during a sandstorm since the thick dust decreases visibility, which causes cars to be driven much more slowly and eventually causes a build-up of vehicles. For Visibility input variable the x-axis is the visibility range in meters that ranges from 100 to 1500 meters. Its linguistic variables are very high, high, medium, low, and very low.

Table 3. Visibility membership function description

Fuzzy Set	Membership Function Type	Parameters
Very Low	Trapezoidal	[0 100 200 350]
Low	Triangular	[100 400 700]
Medium	Triangular	[400 800 1200]
High	Triangular	[900 1200 1500]
Very High	Trapezoidal	[1250 1400 1500 1600]

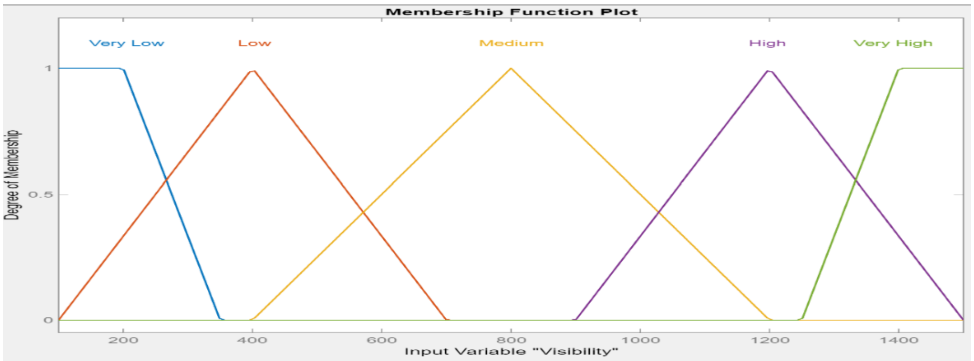

Figure 5. Visibility membership function plot

Extension (Output)

The extension time of the green light in seconds is the output variable of the proposed fuzzy controller, and it will be determined by four linguistic variables: zero, short, medium, and large. It ranges between 0 and 30 seconds.

Table 4. Extension membership function description

Fuzzy Set	Membership Function Type	Parameters
Zero	Trapezoidal	[0 0 2 9]
Short	Triangular	[0 10 20]
Medium	Triangular	[10 20 30]
Large	Trapezoidal	[21 28 30 30]

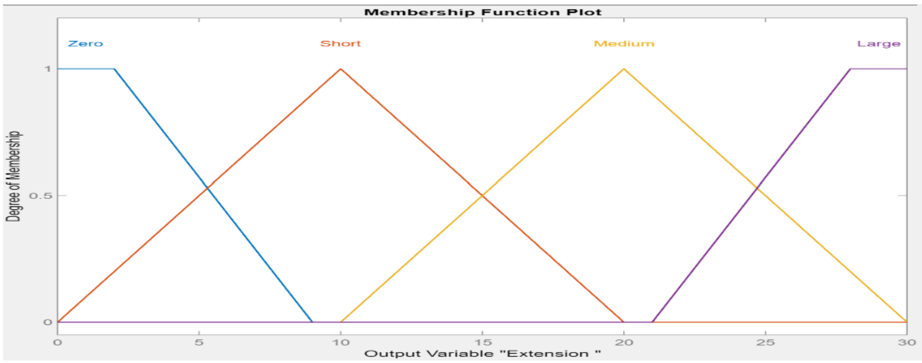

Figure 6. Extension membership function plot

Fuzzy Rules Analysis

Humans create rules to carry out whatever activity they undertake. For instance, if there were a traffic cop on duty at a junction, one from the north and one from the west, he would employ his professional judgment to essentially manage traffic in the following ways: Permit traffic from the north to flow through the city for a longer period of time if it is heavier than traffic from the west. The fuzzy logic controller's inference mechanism and this human cognitive process are comparable. In the development of the fuzzy logic controller, we use almost similar rules and below are some examples:

• If there are too many vehicles at the arrival side and the queue of vehicles is very short at the queuing side and the visibility is medium, then extend the green light longer.
• If there are very few of vehicles at the arrival side and the queue of vehicles is very short at the queuing side and the visibility is very high, then do not extend the green light.

The number of rules can be calculated by multiplying the number of membership functions per input. On the basis of three input variables there are 125 fuzzy rules. Some rules are indicated in Figure 7.

	Rule
1	If Queue is Very Short and Arrival is Very Few and Visibility is Very High then Extension is Zero
2	If Queue is Very Short and Arrival is Very Few and Visibility is High then Extension is Zero
3	If Queue is Very Short and Arrival is Very Few and Visibility is Medium then Extension is Zero
4	If Queue is Very Short and Arrival is Very Few and Visibility is Low then Extension is Short
5	If Queue is Very Short and Arrival is Very Few and Visibility is Very Low then Extension is Medium
6	If Queue is Very Short and Arrival is Few and Visibility is Very High then Extension is Zero
7	If Queue is Very Short and Arrival is Few and Visibility is High then Extension is Zero
8	If Queue is Very Short and Arrival is Few and Visibility is Medium then Extension is Short
9	If Queue is Very Short and Arrival is Few and Visibility is Low then Extension is Medium
10	If Queue is Very Short and Arrival is Few and Visibility is Very Low then Extension is Medium
11	If Queue is Very Short and Arrival is Average and Visibility is Very High then Extension is Short
12	If Queue is Very Short and Arrival is Average and Visibility is High then Extension is Short
13	If Queue is Very Short and Arrival is Average and Visibility is Medium then Extension is Medium
14	If Queue is Very Short and Arrival is Average and Visibility is Low then Extension is Medium
15	If Queue is Very Short and Arrival is Average and Visibility is Very Low then Extension is Large
16	If Queue is Very Short and Arrival is Many and Visibility is Very High then Extension is Medium
17	If Queue is Very Short and Arrival is Many and Visibility is High then Extension is Medium
18	If Queue is Very Short and Arrival is Many and Visibility is Medium then Extension is Large
19	If Queue is Very Short and Arrival is Many and Visibility is Low then Extension is Large

Figure 7. Rule base editor

According to Figure 8, as the Arrival (y axis) and Queue (x axis) decrease, so does the Extension (z axis). Additionally, Figure 9 shows that the Extension increases in response to a decrease in Visibility and an increase in Queue. Similarity can be seen in Figure 10.

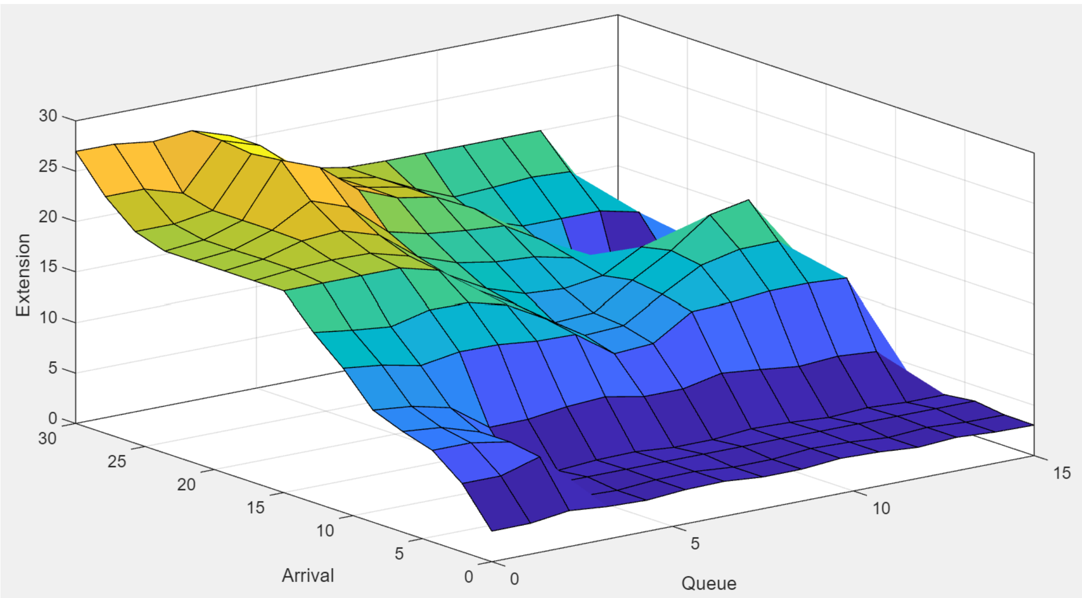

Figure 8. Surface graph of Queue and Arrival vs Extension

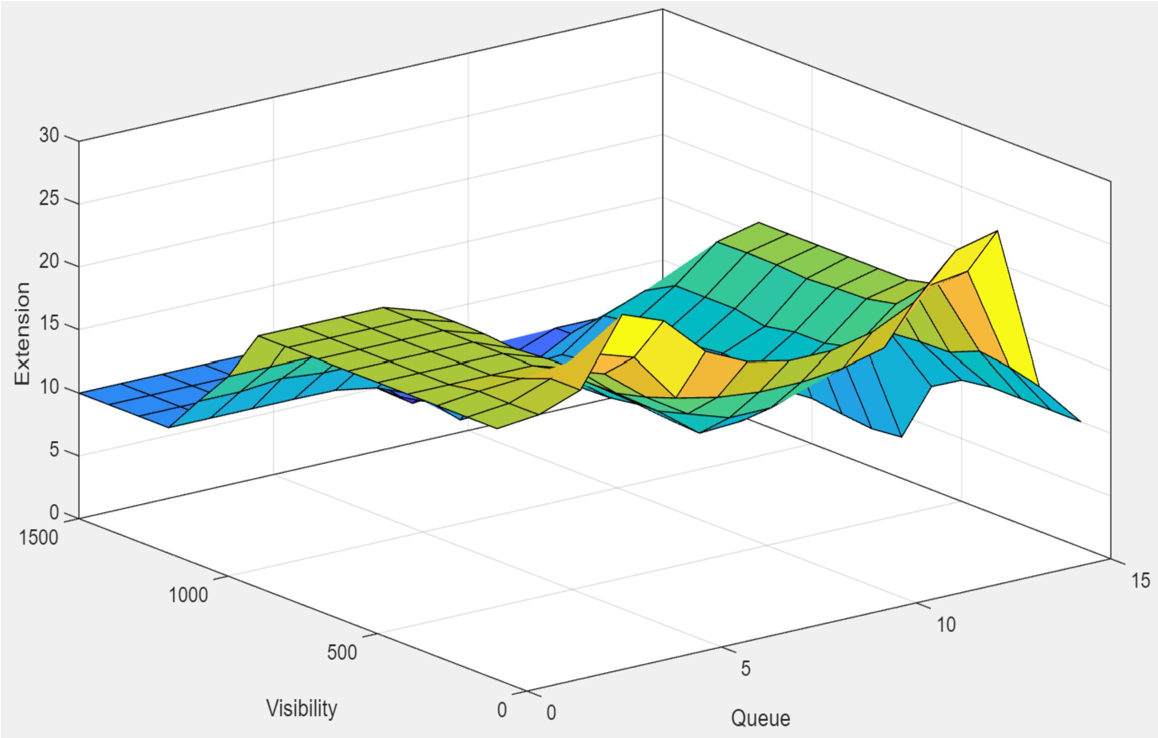

Figure 9. Surface graph of Queue and Visibility vs Extension

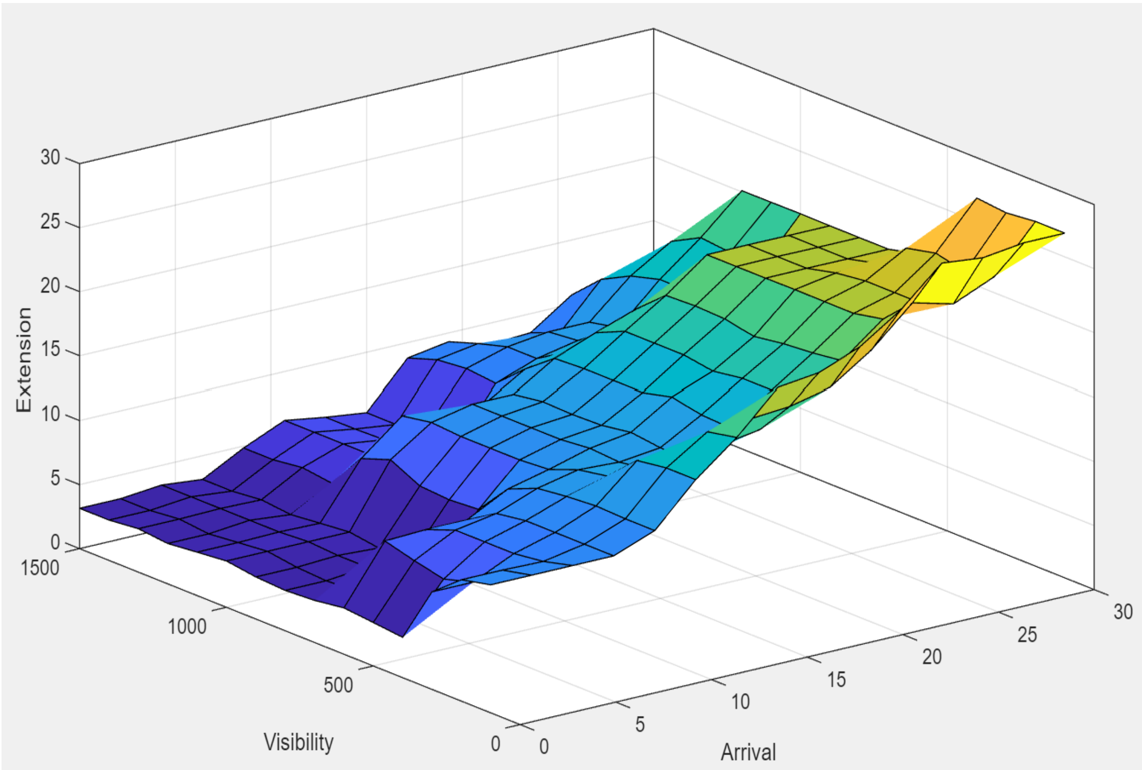

Figure 10. Surface graph of Arrival and Visibility vs Extension

Results and Discussion

A set of crisp values has been added to the fuzzy logic control system, as shown in Figure 11. The variables Queue, Arrival and Visibility have been assigned values of 7, 15 and 800, respectively. The corresponding crisp output is 12.9 seconds.

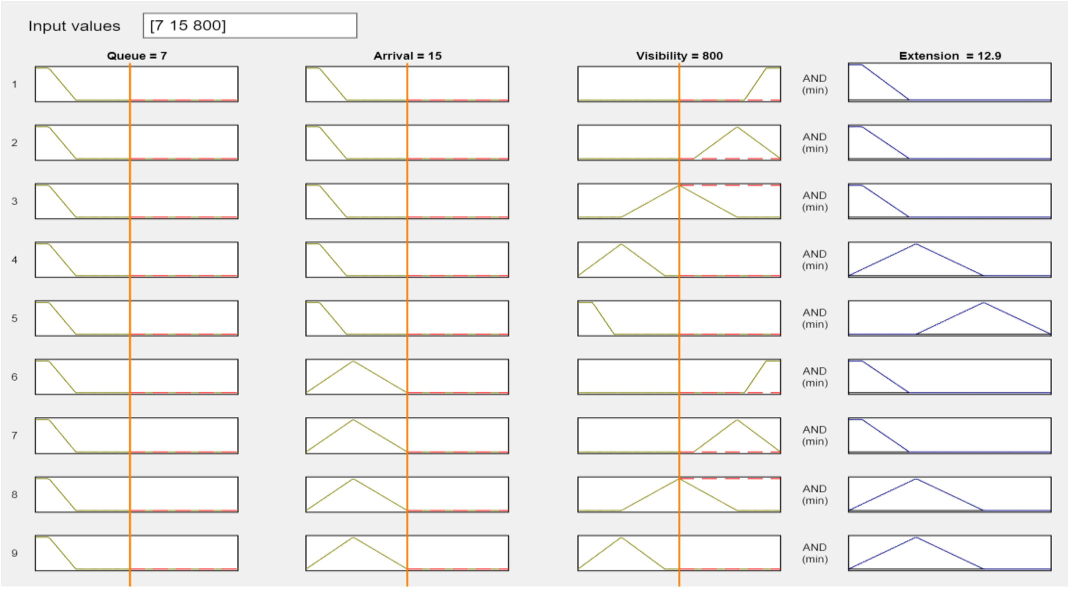

Figure 11. Rule viewer

Following a thorough design process, we test the intelligent traffic light control system and talk about how the input variables affect the output variable, as shown in Table 5. In the ninth and third rows, the Arrival and Visibility remain unchanged, but the Queue grew from 3 to 15, resulting in a drop in the Extension from 26.6 to 13.5. In addition, the Visibility increased from 500 to 1300, resulting in a decrease in the Extension, while the Queue and Arrival in the fifth and sixth rows stay constant.

Table 5. Extension time at different values of input variables

No.	Queue	Arrival	Visibility	Extension
1	3	6	350 m	10 sec
2	3	19	900 m	21.5 sec
3	3	27	500 m	26.6 sec
4	7	14	350 m	12.9 sec
5	10	19	500 m	14.6 sec
6	10	19	1300 m	8.74 sec
7	13	27	900 m	16 sec
8	13	6	350 m	3.39 sec
9	15	27	500 m	13.5 sec

Simulation

The MATLAB simulation (Simulink) was used to evaluate the effectiveness of the fuzzy controller in controlling traffic flow at an isolated intersection as shown in Figure 12.

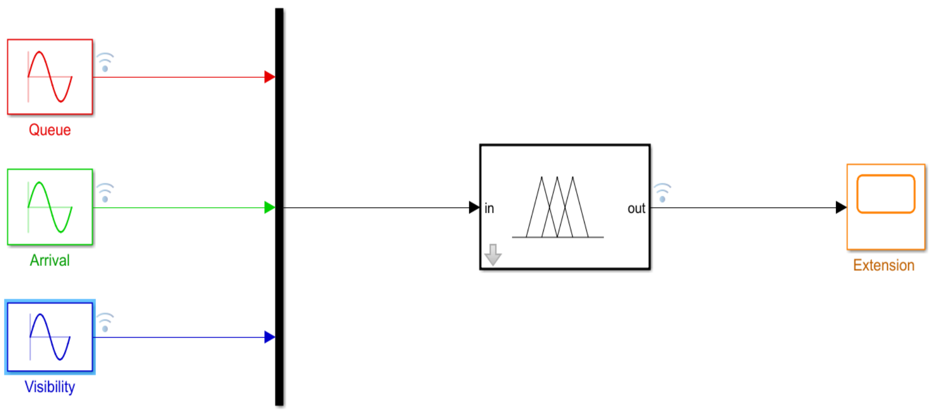

Figure 12. Simulink model

Figures 13, 14 and 15 show that the x-axis represents simulation time, and the y-axis represents the value of the corresponding variable relative to its unit of measurement. Every possibility as stated in the fuzzy rule base is permuted by subjecting each input variable to a sine wave function block with different parameters.

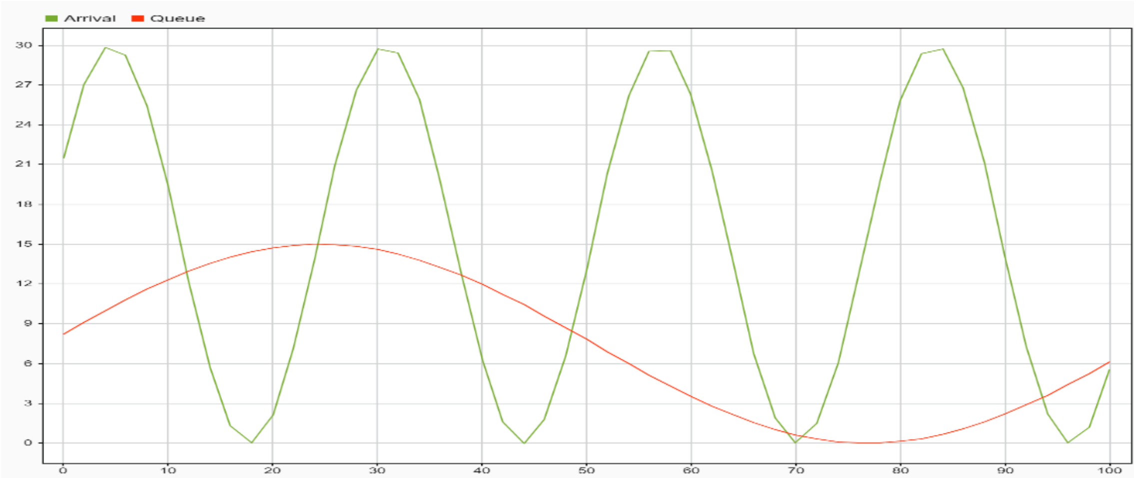

Figure 13. Arrival and Queue in simulink model

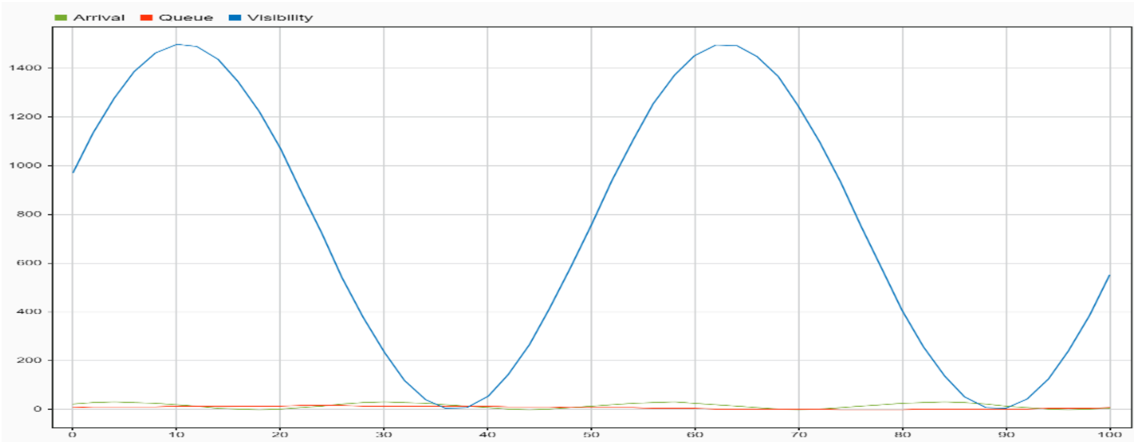

Figure 14. All inputs in simulink model

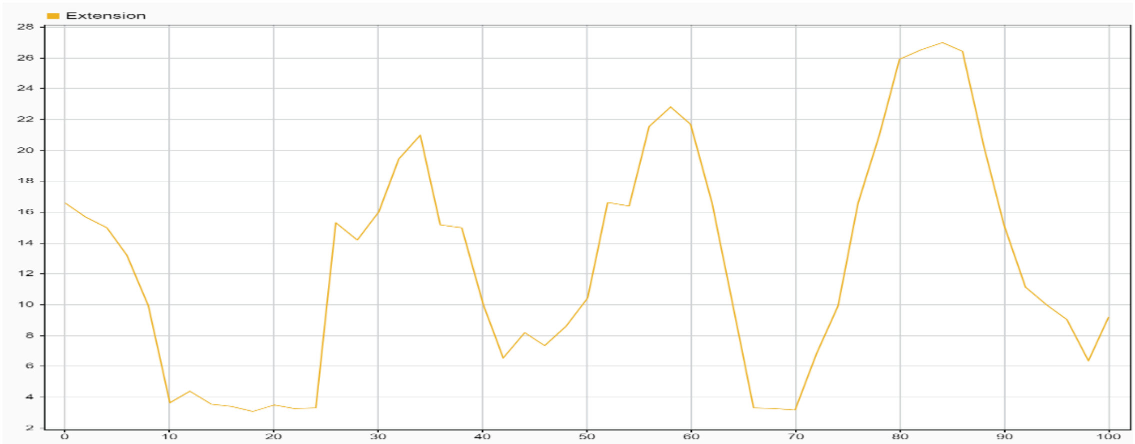

Figure 15. Output in simulink model

Figure 14 illustrates the changes in the values of the input variables throughout the simulation, and Figure 13 clearly depicts the changes in the inputs Queue and Arrival, while Figure 15 displays the output result. From 10 to 18 on the x-axis, we have noticed that when the Queue increased and Arrival reached its lowest point, the extension time dropped to the absolute minimum. On the other hand, the extension time peaked at 27 sec as we move from 78 to 84 on the x-axis, which coincides with an increase in Arrival to its peak, Visibility decreases, and there was a gradual increase in Queue.

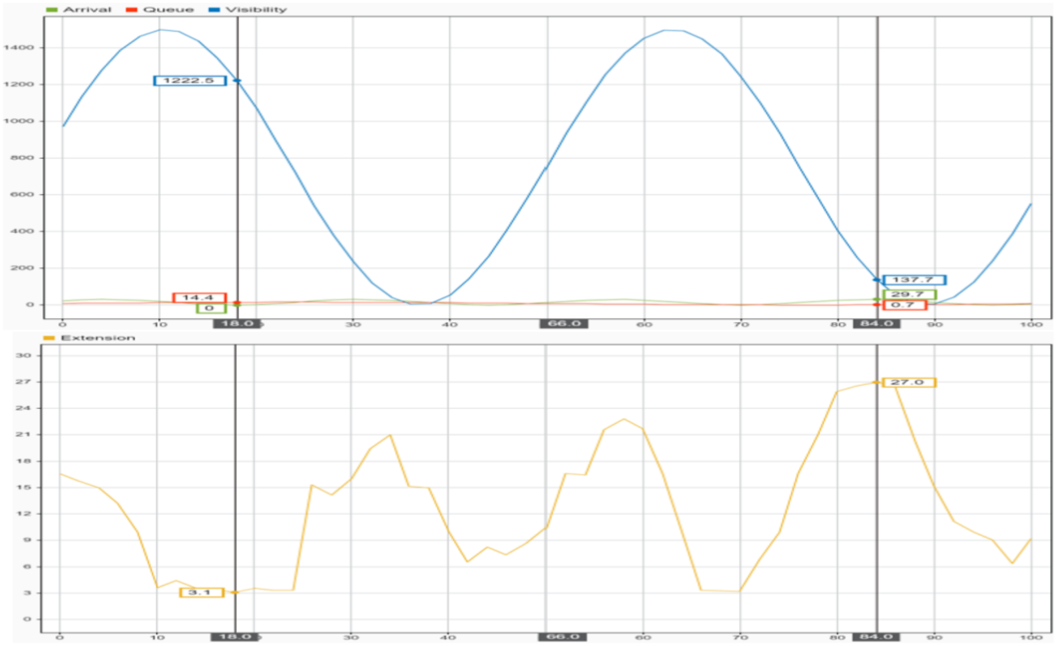

Figure 16. Simulink model with two cursors

Conclusion

In this paper, we gave a fuzzy logic controller to improve the performance of Riyadh's traffic lights controller. Using the suggested fuzzy logic controller, the number of arriving vehicles and queuing vehicles under various weather conditions have been taken into consideration when estimating the green light extension time.

Recommendations

The fuzzy controllers' design and programming are completed. However, to guarantee the accuracy of the rules and attain optimal system performance, expert's knowledge is required.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Advances in Technology and Innovation (www.icati.net) held in Antalya/Turkey on November 14-17, 2024.

References

Alam, J., Pandey, M. K., & Ahmed, H. (2013). Intellegent traffic light control system for isolated intersection using fuzzy logic. In *Conference on Advances in Communication and Control Systems (CAC2S 2013)*,209-215. Retrieved from https://www.atlantis-press.com/article/6306.pdf

Ande, M. M. (1996). *Design of fuzzy logic based adaptive traffic signal controller*. (Master's thesis). Retrieved from UNLV Retrospective Theses & Dissertations.

Chabchoub, A., Hamouda, A., Al-Ahmadi, S., & Cherif, A. (2021). Intelligent traffic light controller using fuzzy logic and image processing. *International Journal of Advanced Computer Science and Applications*, *12*(4), 396-399.

Javatpoint. (n.d.). *Fuzzy logic tutorial*. Retrieved from https://www.javatpoint.com/fuzzy-logic

Omina, J. A. (2015). An intelligent traffic light control system based on fuzzy logic algorithm. *International Academic Journal of Information Systems and Technology*, *1*(5), 1-17.

Pappis, C. P., & Mamdani, E. H. (1977). A fuzzy logic controller for a trafc junction. *IEEE Transactions on Systems Man and Cybernetics*, *7*(10), 707–717.

Priy, S. (2023, January 24). Fuzzy logic introduction. GeeksforGeeks. Retrieved from https://www.geeksforgeeks.org/fuzzy-logic-introduction/

SABQ. (2022, July 26). *Neom will be rolling out in 2024. Crown prince: We have goals to make Saudi Arabia among the top 3 global equity markets*. Retrieved from https://sabq.org/saudia/yf51k3ne48

Salehi, M., Sepahvand, I., & Yarahmadi, M. (2014). TLCSBFL: A traffic lights control system based on fuzzy logic. *International Journal of U- and E- Service Science and Technology*, *8*(3), 27–34.

United States Department of Transportation. (2021, April 27). *Traffic signal timing manual: Chapter 5 - office of operations. Federal Highway Administration*. Retrieved from https://ops.fhwa.dot.gov/publications/fhwahop08024/chapter5.htm

Author Information

Amjaad Alfaifi
Mathematics Department, Faculty of Science, King Saud University. P.O . Box 22452, Riyadh 11495, Saudi Arabia
Contact e-mail: *amjaad_alfaifi@hotmail.com*

Fairouz Tchier
Mathematics Department, Faculty of Science, King Saud University. P.O . Box 22452, Riyadh 11495, Saudi Arabia

To cite this article:

Alfaifi, A., & Tchier, F. (2024). Intelligent traffic lights control system: Riyadh city. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 31*, 31-41.