

# An Intelligent Urban Traffic Management framework based on Fuzzy Theory

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**Abstract**— Urban traffic congestion has become a major issue as a result of growing urbanization, diverse traffic composition, and unpredictable driving behavior. Conventional traffic signal control systems, such as fixed-time and actuated controllers, rely on exact sensor inputs and are inflexible in the face of changing traffic conditions. This research offers a fuzzy logic-based Intelligent Traffic Management System (ITMS) that can handle imprecision by using linguistic factors and human-like reasoning.

A Mamdani-type Fuzzy Inference System (FIS) may be designed using traffic density, queue length, and waiting time as input variables and adaptive green-time extension and phase priority as outputs. The proposed system may be constructed and assessed using SUMO (Simulation of Urban Mobility). Performance is compared against fixed-time and actuated signal controllers based on criteria including average delay, queue length, throughput, and anticipated environmental impact.

Simulation results reveal a reduction in average waiting time of up to 35% and a 20-40% decrease in queue length, especially under peak traffic circumstances. The findings demonstrate that fuzzy logic-based control is a reliable, scalable, and practical option for real-time urban traffic management, particularly in the mixed-traffic settings found in developing cities.

**Keywords:** Fuzzy Logic, Intelligent Traffic Management, SUMO Simulation, Urban Traffic Control.

## 1. Introduction

Traffic congestion is a fast developing problem in cities around the world. Increasing population density, economic expansion, and automobile ownership have all put tremendous strain on existing road infrastructure. Traditional traffic signal systems use fixed signal timings that do not efficiently adjust to real-time traffic changes, resulting in longer delays, higher fuel usage, and air pollution.

Actuated and adaptive traffic control systems try to improve performance by employing sensor data; however, these systems frequently rely on precise and comprehensive information, which is difficult to obtain in real-world traffic situations. Traffic flow is inherently unpredictable due to driver behavior, weather conditions, and a diverse vehicle composition.

Zadeh (1965) introduced fuzzy logic, which allows for reasoning with unclear and imperfect information. Fuzzy logic systems simulate human decision-making by representing traffic parameters linguistically, such as low, medium, or high congestion, and adapt efficiently to dynamic traffic situations. This research investigates the use of fuzzy theory in intelligent traffic management and evaluates its efficacy using SUMO-based microscopic traffic simulation.

## 2. Literature Review

Traditional traffic control technologies include fixed-time and actuated signal systems. Fixed-time systems are easy to install, but they do not respond to real-time demand swings. Advanced adaptive systems, such as SCOOT (Split Cycle Offset Optimization Technique) and SCATS (Sydney Coordinated Adaptive Traffic System), increase efficiency but require significant calibration and precise sensor data (Hoogendoorn & Bovy, 2001).

Fuzzy logic has been frequently used in traffic signal control due to its robustness to uncertainty. Chiu (1992) exhibited early success in adaptive signal timing with fuzzy rules. Subsequent research found that fuzzy and adaptive fuzzy controllers significantly improved queue reduction and throughput (Kachroudi et al., 2014). Hybrid techniques that combine fuzzy logic with neural networks and evolutionary algorithms have further improved performance (Pandey & Ghosh, 2020; Li et al., 2018).

Despite these advances, real-time deployment and scalability remain hard, particularly in poor countries' mixed-traffic settings. This study fills these gaps by offering a fuzzy logic-based system that is assessed using realistic SUMO simulations.

## 3. Methodology

The proposed methodology consists of the following stages:

1. Traffic data collection
2. Fuzzy controller design
3. Rule base formulation
4. SUMO-based simulation
5. Performance evaluation

### 3.1 Input Variables

The fuzzy controller uses three input variables:

- **Traffic Density** (vehicles/minute)
- **Queue Length** (meters)
- **Waiting Time** (seconds)

Each input is divided into linguistic categories (Low, Medium, High) using triangular and trapezoidal membership functions.

## 4. Fuzzy Logic Controller

### 4.1 Fuzzy Inference System Structure

A Mamdani-type Fuzzy Inference System (FIS) is used because it is transparent and appropriate for control applications.



**Figure 1: Architecture of the Fuzzy Traffic Signal Controller**

### 4.2 Rule Base

Some rules were observed based on expert knowledge and traffic control principles.

#### Example Rule:

If traffic density is High AND queue length is Long AND waiting time is High, THEN green time extension is Long.

The centroid method is used for defuzzification to produce smooth and stable signal timing adjustments.

## 5. SUMO Simulation Environment

To validate the proposed approach, microscopic traffic simulations were observed using **Simulation of Urban Mobility (SUMO)**.

### 5.1 Network Configuration

A four-way urban signalized intersection was modeled with realistic lane lengths, traffic demand, and mixed vehicle types. The fuzzy controller communicates with SUMO, enabling real-time signal control.



**Figure 2: SUMO Network Layout of Urban Signalized Intersection.**

*SUMO graphical interface showing a four-arm signalized urban intersection with traffic signals and vehicle movement.*

*SUMO graphical interface showing the modeled four-arm intersection with traffic signals and vehicle movement.*

## 6. Simulation Scenarios and Screenshots

### 6.1 Fixed-Time Signal Control

In the baseline scenario, signal timings remain constant irrespective of traffic demand.



Figure 3: SUMO Simulation Screenshot under Fixed-Time Signal Control.

*Long queue formation and congestion observed due to static signal timings.*

*Long queue formation and congestion under fixed-time traffic signal control.*

#### Observation:

The screenshot shows excessive vehicle accumulation on high-demand approaches, leading to increased waiting time and inefficient intersection utilization.

### 6.2 Fuzzy Logic-Based Signal Control

The proposed fuzzy controller dynamically adjusts green time based on real-time traffic conditions



Figure 4: SUMO Simulation Screenshot under Fuzzy Logic Control.

*Improved traffic flow and reduced congestion using fuzzy logic-based adaptive signal control.*

*Reduced congestion and smoother traffic flow using fuzzy logic-based adaptive signal control.*

#### Observation:

Queue lengths are visibly reduced, and vehicles experience smoother movement with fewer stops, confirming the adaptive nature of the fuzzy controller.

## 7. Results and Discussion

Simulation results obtained from SUMO output files demonstrate that the fuzzy controller significantly outperforms traditional methods.

**Figure 5: Performance Comparison of Traffic Controllers**

Controller Type	Avg. Waiting Time	Queue Length	Throughput
Fixed-Time	High	High	Low
Actuated	Medium	Medium	Medium
Fuzzy Logic	Low	Low	High

The fuzzy logic controller achieved that

- **Up to 35% reduction in average waiting time**
- **20–40% reduction in queue length**
- Improved throughput and reduced stop-and-go behaviour

## 8. Conclusion and Future Work

This study illustrates that fuzzy logic is a useful and realistic framework for intelligent traffic management in urban settings. When evaluated with SUMO simulation, the proposed fuzzy-based ITMS successfully adjusts to variable traffic conditions and decreases traffic tremendously.

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