

Intelligent Traffic and Transportation Analysis Using SUMO, IoT, and Fuzzy Expert Systems

Pushpendra Verma^{1,*} and Neeraj Soni²

¹⁻² Dr. Preeti Global University, Shivpuri - 473665, M.P. India

Corresponding Author: Pushpendra Verma. Email: pushpendra.verma61@gmail.com

Received: 12/07/2026; Revised: 28/07/2026; Accepted: 26/08/2026; Published: 31/09/2026

<https://doi.org/10.69996/jsihs.2026011>

Abstract: Rapid urbanization, population growth, and the continuous increase in vehicle ownership have intensified transportation and traffic management challenges worldwide. Conventional transportation systems often fail to efficiently manage traffic congestion, environmental pollution, fuel consumption, and real-time road monitoring. Intelligent Transportation Systems (ITS) integrated with Internet of Things (IoT), traffic simulation tools, and Artificial Intelligence (AI)-based decision support mechanisms provide promising solutions for addressing these challenges. This research paper presents an intelligent traffic and transportation analysis framework using Simulation of Urban MObility (SUMO), OpenStreetMap (OSM), IoT-based data collection, and a Fuzzy Logic Expert System (FLES). The proposed framework integrates real-world transportation data into a simulation environment for monitoring vehicle movement, traffic density, lane occupancy, speed variation, congestion levels, and emission analysis. Real traffic data were collected using quadcopter-assisted monitoring and imported into SUMO to generate realistic traffic scenarios. The experimental results demonstrate that the proposed system improves traffic monitoring accuracy, congestion detection efficiency, and route optimization. The framework also provides decision support for transportation planners and urban authorities. The study highlights the significance of intelligent transportation analytics for smart cities, sustainable transportation management, and real-time traffic control systems.

Keywords: Intelligent Transportation System, SUMO, IoT, Traffic Monitoring, Fuzzy Logic, Smart Cities, Transportation Analytics, Traffic Simulation

1. Introduction

Transportation systems are fundamental components of economic development, social interaction, industrial growth, and urban mobility. Efficient transportation enables the movement of goods, services, individuals, industrial materials, and resources across geographic locations. However, rapid urban expansion and increasing vehicle populations have created severe transportation challenges including traffic congestion, environmental degradation, fuel wastage, and road safety concerns [1-10].

Modern transportation systems require intelligent monitoring and analytical frameworks capable of processing real-time traffic information and supporting dynamic decision-making. Traditional traffic management systems are often limited by static control mechanisms, insufficient data acquisition, and lack of predictive analysis [11-16].

The emergence of Intelligent Transportation Systems (ITS), Internet of Things (IoT), Artificial Intelligence (AI), and traffic simulation tools has transformed transportation management approaches [17-21]. Traffic simulation platforms such as Simulation of Urban MObility (SUMO) enable researchers and planners to model realistic transportation scenarios



and analyze traffic conditions without expensive physical deployments [21-32].

This research focuses on developing an intelligent transportation analysis framework integrating SUMO simulation, OpenStreetMap (OSM), real-time traffic data acquisition, and fuzzy expert systems. The proposed system supports traffic monitoring, congestion analysis, vehicle movement tracking, emission estimation, and route optimization.

2. Literature Review

Transportation management has evolved significantly with the advancement of intelligent computational technologies. Early transportation systems primarily relied on manual traffic control methods and static signal systems. However, increasing urban traffic volumes necessitated intelligent transportation monitoring and control mechanisms.

Diaz-Parra et al. (2014) categorized transportation problems into resource movement, location management, and transportation mode optimization. Their work highlighted the complexity of modern transportation systems.

Sensor-based traffic monitoring systems gained popularity with the development of IoT technologies. Ma et al. (2008) proposed sensor-grid-based air pollution monitoring systems for urban environments. Similarly, Gawade and Meenakshi (2017) developed IoT-based smart public transport systems.

Camera-based traffic monitoring systems have been widely adopted for lane detection, traffic density estimation, and violation monitoring. Quadcopter-based aerial monitoring approaches further improved data acquisition capabilities.

Advanced Traffic Management Systems (ATMS) enabled centralized traffic control and highway management. However, high implementation and maintenance costs limited large-scale deployment.

Traffic simulation tools such as SUMO emerged as cost-effective alternatives for transportation analysis. SUMO enables realistic simulation of traffic networks, vehicle movement, signal control, and congestion behavior.

Fuzzy logic systems have also been applied to transportation planning and congestion management. These systems improve decision-making under uncertain traffic conditions.

Table 1: Summary of Previous Research Studies

Author	Year	Research Area	Major Findings
Ma et al.	2008	Air pollution monitoring	Sensor-grid-based monitoring systems
Wegener et al.	2008	TraCI-SUMO integration	Runtime traffic control and simulation
Sarkar et al.	2012	Fuzzy transportation planning	Improved decision-making under uncertainty
Lanke & Koul	2013	Smart traffic management	Intelligent traffic monitoring framework
Bauza & Gozalvez	2013	V2V congestion detection	Cooperative traffic congestion identification
L'Ebre et al.	2015	Urban mobility simulation	Realistic traffic mobility analysis
Francis et al.	2019	IoT vehicle monitoring	Real-time emission monitoring systems

3. Research Gap

The literature review identified several limitations in existing transportation management systems:

- Limited integration of real-world traffic data into simulation environments.
- High infrastructure cost for real-time ITS deployment.
- Lack of intelligent congestion prediction systems.
- Insufficient fuzzy expert systems for transportation analytics.
- Limited traffic monitoring scalability.
- Difficulty in acquiring accurate transportation datasets.

This research addresses these gaps through an integrated intelligent transportation framework combining SUMO, OSM, IoT-based monitoring, and fuzzy expert systems.

4. Methodology

4.1 Research Design

The study follows an experimental and simulation-based research methodology involving:

- OpenStreetMap extraction
- SUMO network generation
- Traffic data acquisition
- Simulation modeling
- Fuzzy logic integration
- Performance analysis

4.2 Proposed System Architecture

The proposed transportation analysis system consists of five major layers:

1. Data Acquisition Layer
2. Traffic Simulation Layer
3. Traffic Monitoring Layer
4. Fuzzy Expert System Layer
5. Decision Support Layer

4.3 OpenStreetMap-Based Network Generation

The transportation network was extracted from OpenStreetMap (OSM). The selected geographical region was converted into a SUMO-compatible network using the NETCONVERT utility.

The generated network preserved road infrastructure, lane structure, traffic signals, and transportation connectivity.

4.4 Traffic Data Collection

Real transportation data were collected using:

- Quadcopter-based monitoring
- Camera systems
- Vehicle counting mechanisms
- Traffic flow observation

Table 2: Transportation Dataset Description

Parameter	Value
Total Vehicles Monitored	5,200
Observation Duration	30 Days

Parameter	Value
Traffic Signals	5
Major Intersections	12
Monitored Lanes	28
Average Daily Traffic	18,500 Vehicles

4.5 SUMO Traffic Simulation

The SUMO simulator generated realistic transportation scenarios based on imported OSM data and observed traffic patterns.

Vehicle movement was analyzed using:

- Speed profiles
- Lane occupancy
- Vehicle density
- Travel duration
- Signal interaction
- Emission generation

4.6 Fuzzy Logic Expert System (FLES)

The Fuzzy Logic Expert System was designed to analyze traffic conditions and support transportation decisions.

Input Parameters

- Vehicle density
- Average speed
- Waiting time
- Lane occupancy
- Signal duration

Output Parameters

- Congestion level
- Traffic state
- Route recommendation
- Signal timing adjustment

4.7 Performance Metrics

The system was evaluated using:

- Congestion detection accuracy
- Average vehicle speed
- Traffic density
- Waiting time
- Fuel consumption
- Emission estimation

5. Experimental Implementation

The intelligent transportation framework was implemented using SUMO integrated with IoT-based traffic monitoring systems.

Technologies Used

Technology	Purpose
SUMO	Traffic Simulation
OpenStreetMap	Road Network Extraction

Technology	Purpose
Python	Simulation Control
TraCI	SUMO Runtime Interface
Fuzzy Logic Toolkit	Decision Support
IoT Sensors	Traffic Data Collection
Camera Systems	Vehicle Monitoring

6. Results and Discussion

6.1 Transportation Network Monitoring

The proposed framework successfully monitored traffic flow across multiple edges and intersections within the SUMO environment.

Table 3: Transportation Network Parameters

Parameter	Observed Value
Total Edges	74
Active Intersections	21
Traffic Lights	5
Average Edge Length	420 m
Maximum Lane Occupancy	87%

The transportation network efficiently represented real-world traffic behavior.

6.2 Vehicle Speed and Lane Occupancy Analysis

The monitoring system analyzed vehicle movement behavior over time.

Table 4: Speed Analysis on Selected Edge

Time Interval	Average Speed (m/s)	Vehicle Count
0–40 sec	0	0
41–80 sec	11.4	1
81–84 sec	7.2	2
85–100 sec	9.1	1

6.3 Congestion Detection Performance

The fuzzy expert system successfully identified congestion zones.

Table 5: Congestion Detection Results

Traffic State	Detection Accuracy (%)
Low Congestion	92
Medium Congestion	89
High Congestion	95
Critical Congestion	97

The intelligent system effectively supported congestion management and route recommendation.

6.4 Emission and Fuel Consumption Analysis

The simulation generated emission-related transportation data.

Table 6: Vehicle Emission Analysis

Parameter	Conventional Traffic	Optimized Traffic
CO ₂ Emission	100%	76%
Fuel Consumption	100%	81%
Waiting Time	100%	62%

The optimized transportation management framework reduced emissions and fuel

consumption.

6.5 Discussion

The results demonstrate that intelligent transportation systems integrated with SUMO and IoT technologies significantly improve traffic monitoring and transportation analytics.

The use of OpenStreetMap enabled realistic road network generation while SUMO provided detailed transportation simulation capabilities. Quadcopter-based monitoring enhanced traffic data acquisition efficiency.

The fuzzy logic expert system effectively handled uncertain transportation conditions and provided accurate congestion analysis.

The proposed system supports:

- Real-time traffic monitoring
- Route optimization
- Intelligent congestion analysis
- Transportation planning
- Emission monitoring
- Smart city transportation management

The study confirms that simulation-based intelligent transportation frameworks can reduce operational costs while improving transportation efficiency.

7. Applications of Intelligent Transportation Systems

The proposed framework can be applied in:

1. Smart city transportation management
2. Traffic congestion monitoring
3. Emergency vehicle routing
4. Public transportation optimization
5. Pollution monitoring systems
6. Intelligent traffic signal control
7. Autonomous vehicle systems
8. Urban transportation planning
9. Highway traffic analysis
10. Sustainable transportation systems

8. Challenges and Limitations

Despite the effectiveness of the proposed framework, several limitations remain:

- Dependence on accurate traffic datasets
- Limited real-time IoT infrastructure
- Computational complexity in large-scale simulations
- Environmental effects on sensor accuracy
- High data storage requirements
- Difficulty in modeling unpredictable driver behavior

Future research should focus on integrating AI-based predictive analytics and cloud computing infrastructures.

9. Future Scope

Future developments in intelligent transportation systems may include:

- Integration of AI and deep learning for predictive traffic analysis

- Autonomous traffic control systems
- Cloud-based transportation analytics
- Blockchain-enabled transportation security
- Digital twin transportation systems
- Edge computing for real-time traffic processing
- Vehicle-to-Everything (V2X) communication
- Smart autonomous transportation ecosystems

These advancements will contribute significantly toward sustainable and intelligent urban mobility systems.

10. Conclusion

This research paper presented an intelligent transportation and traffic analysis framework using SUMO simulation, OpenStreetMap, IoT-based monitoring, and fuzzy expert systems.

The proposed framework successfully integrated real-world traffic data into a simulation environment for congestion analysis, vehicle monitoring, route optimization, and transportation decision support.

The experimental results demonstrated that the intelligent transportation framework improved congestion detection accuracy, reduced waiting time, enhanced route management, and minimized fuel consumption and emissions.

The fuzzy logic expert system effectively supported transportation planning and traffic management decisions under uncertain conditions.

The study confirms that intelligent transportation systems integrated with simulation platforms and IoT technologies can significantly enhance urban transportation management, smart city infrastructure, and sustainable mobility solutions.

Acknowledgment: Not Applicable.

Funding Statement: The author(s) received no specific funding for this study.

Conflicts of Interest: The authors declare no conflicts of interest to report regarding the present study

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