

Navigation-Integrated Smart Traffic Light System for Emergency Vehicles

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Abstract

This project presents a prototype-based smart traffic light system designed to provide priority passage for emergency vehicles at urban intersections. The system was developed using an Arduino Uno, LED traffic lights, and an HC-SR04 ultrasonic sensor to detect approaching emergency vehicles and automatically change traffic signals. A model intersection was constructed including a hospital, roads, traffic lights, and toy vehicles. Experiments were conducted under three different traffic conditions: open traffic, moderate traffic, and heavy traffic. Each scenario was tested three times under both normal traffic light operation and smart system operation. The results showed that the smart traffic light system reduced ambulance travel times in all traffic conditions. The average travel time decreased from 43 seconds to 16 seconds in open traffic, from 52 seconds to 25 seconds in moderate traffic, and from 98 seconds to 48 seconds in heavy traffic. These results demonstrate that emergency vehicle priority systems can significantly reduce delays and improve traffic efficiency. The proposed system provides a practical prototype for future smart city applications and may contribute to faster emergency response and improved public safety.

Keywords

Smart traffic systems, emergency vehicles, Arduino, sensor technologies, green corridor, smart city applications

1. Introduction

Today, traffic lights usually work with fixed timing systems, and emergency vehicles may get stuck because of other vehicles in traffic. With the development of GPS and navigation technologies, it has become possible to track the real-time locations of vehicles. This creates an important opportunity to make traffic systems smarter and more efficient. In this project, a communication system between emergency vehicles and traffic lights is proposed. In this way, before the emergency vehicle reaches an intersection, the traffic lights on the route can turn green. After the vehicle passes, the traffic lights return to their normal operation.

1.1 Objectives

- To reduce the urban travel time of emergency vehicles.
- To automatically control traffic lights according to the ambulance route.
- To create a green corridor system for uninterrupted passage.
- To use sensors, and smart traffic technologies together.
- To develop an applicable prototype for smart city systems.
- To inform drivers in advance by sending emergency warnings to vehicle screens in future studies.

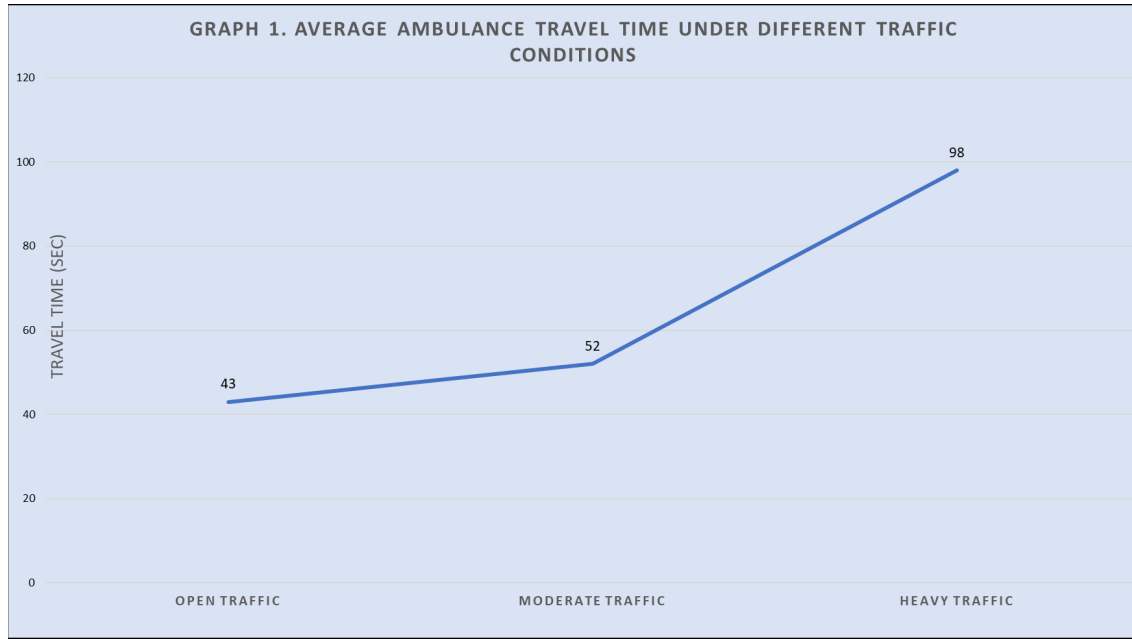


Figure 1. Average Ambulance Travel Time Under Different Traffic Conditions

Figure 1 presents the average ambulance travel times measured during prototype testing under three different traffic density scenarios. The results indicate that ambulance travel time increases significantly as traffic density increases. Under heavy traffic conditions, the ambulance required more than twice the travel time observed under open traffic conditions (Table 1).

Table 2. Traffic vs Arrival Time

Traffic Condition	Average Arrival Time
Open Traffic	43 sec
Moderate Traffic	52 sec
Heavy Traffic	98 sec

1.2. Research Questions

1. Can traffic lights be controlled using navigation data?
2. Can this system reduce the waiting time of emergency vehicles in traffic?
3. Can traffic flow be improved by adjusting traffic lights in advance?
4. Can this system cause problems such as malfunctions or disruptions in traffic lights?

2. Literature Review

Smart city technologies and smart traffic management systems have developed rapidly in recent years. Today, traffic lights are no longer only systems that work with fixed timing. They have become smarter with sensors, artificial intelligence, and real-time data analysis.

Research shows that delays experienced by emergency vehicles can significantly affect response effectiveness and public safety. Therefore, systems that allow ambulances, fire trucks, and police vehicles to receive priority at traffic lights have been developed in many countries (*U.S. Department of Transportation, 2020*).

In another study, RFID, GPS, and sensors were used to detect the approach of emergency vehicles to intersections, and the traffic lights were managed accordingly. This study shows the importance of sensor and location information for emergency vehicles. (Nellore & Hancke, 2016).

Studies are also being carried out in Türkiye in this field. In a study published in Gazi University Journal of Science, a machine learning-based traffic light optimization system that prioritizes emergency vehicles was examined. The study reported that average waiting time could be reduced by 20%, traffic capacity could be increased by 15%, and total travel time could be reduced by 18%. (Yılmaz, Y. ,2025).

According to the Intelligent Transportation Systems Knowledge Resources of the U.S. Department of Transportation, smart traffic signal control can reduce emergency vehicle travel time by up to 62.85% in some scenarios. These results show that smart traffic systems are important not only for traffic order but also for protecting human life. (U.S. Department of Transportation, 2020).

However, many of these systems require expensive infrastructure, advanced software, and citywide installation. Therefore, they may not be easy to apply in every city. This project aims to show the same basic idea with a simpler, more understandable, and education-oriented prototype.

In this project sensors, smart traffic lights, and the green corridor system are combined. Thus, a low-cost and developable smart city model is proposed to help emergency vehicles move faster.

3. Methods

In this project, a model-based prototype was prepared to show a navigation-integrated smart traffic light system for emergency vehicles. First, a small city intersection was created using foam board and model-making materials. The model included roads, traffic lights, a hospital, an ambulance vehicle, and multiple toy vehicles representing different traffic conditions. An Arduino-based electronic system was used to control traffic lights. Red, yellow, and green LED lights represented the traffic lights. Sensors and an Arduino-based control system were used to detect the approach of the ambulance. The prototype mainly focused on sensor-based emergency vehicle detection, while GPS integration was proposed as a future smart city application. When the ambulance approached the determined area, the traffic lights in the ambulance direction turned green, and the traffic lights in the other directions turned red. In this way, a green corridor system was created so that the ambulance could move without stopping. The project also included ideas for future development, such as monitoring traffic density by drone, sending warnings to vehicle screens, and using AI-supported traffic density analysis. With the prepared prototype model, the basic working principle of emergency vehicle priority systems and smart traffic management technologies was demonstrated in a visual and practical way (Figure 2, 3, 4 and 5).

4. Materials Used

- Foam board for the hospital building and other model parts.
- Toy ambulance and small toy cars.
- Road marking tape.
- Arduino Uno.
- Red LED lights.
- Yellow LED lights.
- Green LED lights.
- Resistors (2 pieces, 330 ohm).
- Perforated PCB board.
- Battery or power supply.
- HC-SR04 ultrasonic sensor.
- On-off button.
- Jumper wires.

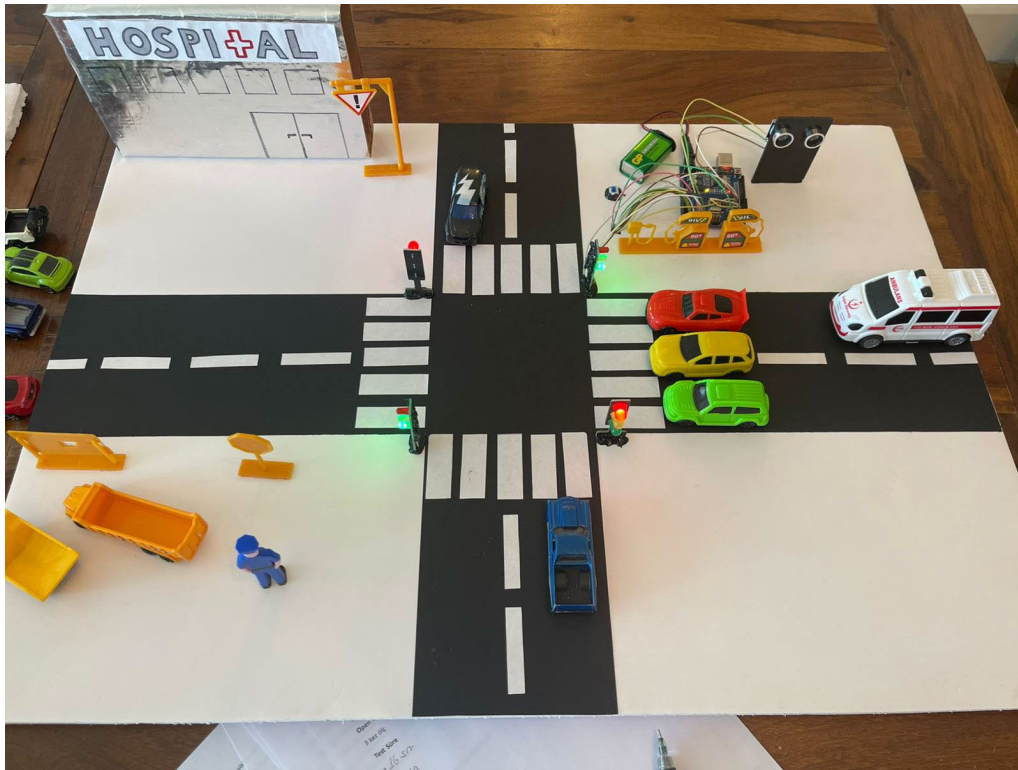


Figure 2. Open Traffic Scenario Used in Prototype Testing



Figure 3. Moderate Traffic Scenario Used in Prototype Testing



Figure 4. Heavy Traffic Scenario Used in Prototype Testing

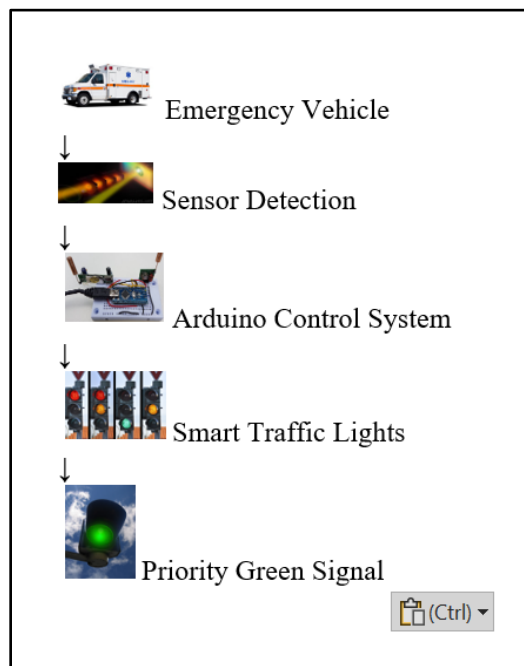


Figure 5. Smart Traffic Light System Architecture

The system architecture shows the basic operating logic of the prototype. When the emergency vehicle approaches the intersection, the sensor detects the vehicle and sends a signal to the Arduino-based control system. The traffic lights then automatically change to provide priority passage for the emergency vehicle.

5. System Operating Principle

- 1) The system normally operates according to the standard traffic light sequence. The traffic lights change between red, yellow, and green at predefined intervals.
- 2) An ultrasonic sensor continuously monitors the approach area of the intersection.
- 3) When the ambulance enters the sensor detection zone, the sensor sends a signal to the Arduino-based control system.
- 4) The Arduino controller processes the sensor signal and activates the emergency traffic mode.
- 5) The traffic lights in the direction of the ambulance turn green, allowing the ambulance to pass without stopping.
- 6) At the same time, the traffic lights in the other directions turn red to prevent traffic conflicts and improve safety.
- 7) This creates a temporary green corridor at the intersection and provides priority passage for the emergency vehicle.
- 8) After the ambulance leaves the detection area, the system automatically returns to the normal traffic light sequence.
- 9) In future versions, GPS and navigation technologies may be integrated to identify the ambulance route and coordinate multiple intersections automatically.
- 10) Additional future improvements may include AI-supported traffic analysis, real-time traffic monitoring, and driver warning systems.

6. Data Collection

Different traffic scenarios were tested on the prototype model.

When the emergency mode was activated, the traffic lights at the model intersection changed automatically, allowing the toy ambulance to move continuously without stopping.

Three different traffic density scenarios were created on the prototype model:

- Open Traffic Scenario
- Moderate Traffic Scenario
- Heavy Traffic Scenario

Different numbers of toy vehicles were used in each scenario to simulate traffic density. The ambulance travel time and waiting time at the intersection were measured using a stopwatch.

For each traffic scenario, the experiment was repeated three times under:

1. Normal traffic light operation
2. Smart traffic light system operation

The collected data were compared to evaluate the effectiveness of the smart traffic light system in reducing emergency vehicle waiting time and improving traffic flow (Table 2 and 3).

Table 3. Prototype Traffic Scenarios

Traffic Scenario	Number of Vehicles	Traffic Density
Open Traffic	3	Low
Moderate Traffic	6	Medium
Heavy Traffic	12	High

Table 4. Experimental Results and System Improvement

Traffic Scenario	Normal System (sec)	Smart System (sec)	Improvement (%)
Open Traffic	43	16	62.8
Moderate Traffic	52	25	51.9
Heavy Traffic	98	48	51.0

The results show that the smart traffic light system reduced ambulance travel times under all traffic conditions. The greatest improvement was observed in the open traffic scenario, while improvements of over 50% were achieved in both moderate and heavy traffic conditions.

7. Findings and Discussion

The experimental results demonstrated that traffic density has a significant effect on ambulance travel time. Under normal traffic light operation, ambulance travel times increased from 43 seconds in open traffic conditions to 98 seconds in heavy traffic conditions.

After activating the smart traffic light system, ambulance travel times were significantly reduced in all traffic scenarios. The average travel time decreased from 43 seconds to 16 seconds in open traffic, from 52 seconds to 25 seconds in moderate traffic, and from 98 seconds to 48 seconds in heavy traffic conditions.

These results indicate that sensor-based traffic light control can effectively reduce delays for emergency vehicles and improve intersection efficiency. The improvement rates exceeded 50% in all tested scenarios, demonstrating the potential of intelligent traffic management systems in smart city applications.

However, real-life implementations of such systems would require additional technologies, including internet communication infrastructure, accurate GPS integration, and software security measures to ensure reliable operation.

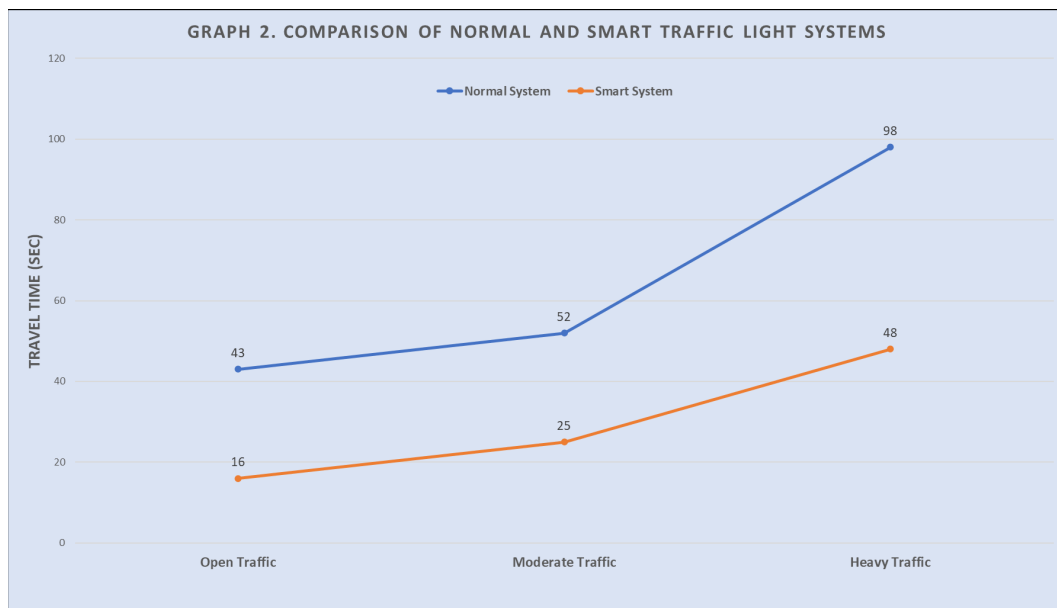


Figure 6. Comparison of Normal and Smart Traffic Light Systems

Figure 6 compares the ambulance travel times under normal traffic light operation and smart traffic light operation. The results clearly show that the smart traffic light system reduced travel times in all traffic scenarios by providing priority passage for the emergency vehicle.

7.1 Prototype Limitations

This prototype represents a simplified model of a smart traffic management system. The current model is limited to a single intersection and manually simulated traffic movement. In addition, the prototype does not include real-time internet communication or full GPS integration.

However, the prototype successfully demonstrates the basic working principle of emergency vehicle priority systems and provides an educational model for future smart city applications.

7.2 Suggested Improvements

1. AI-supported traffic analysis can be added.
2. Real-time traffic data can be integrated into the system.
3. The entire city infrastructure can be connected to the system.
4. A special signal system can be developed for emergency vehicles.
5. Drone support can be used to monitor and analyze traffic density from the air.
6. GPS and navigation technologies can be integrated to identify ambulance routes and coordinate multiple intersections automatically.

7.3 AI-Supported Traffic Optimization

In future smart city applications, artificial intelligence (AI) systems can be integrated into the traffic management infrastructure. AI-supported systems may analyze traffic density, emergency vehicle location, and intersection conditions in real-time. For example, if traffic density increases at a certain intersection, the system may automatically extend the green light duration for emergency vehicles. AI systems may also predict the fastest route by analyzing historical traffic data and current traffic conditions. Such technologies can help reduce emergency response times, improve traffic flow, and increase urban transportation safety.

8. Conclusion

This study presented a navigation-integrated smart traffic light system designed to improve the movement of emergency vehicles at urban intersections. A working prototype was developed using an Arduino microcontroller, traffic light modules, and an ultrasonic sensor to simulate emergency vehicle detection and traffic signal control. Experimental testing was conducted under open, moderate, and heavy traffic conditions. The results demonstrated that the smart traffic light system significantly reduced ambulance travel times in all scenarios. The average travel time decreased from 43 seconds to 16 seconds in open traffic, from 52 seconds to 25 seconds in moderate traffic, and from 98 seconds to 48 seconds in heavy traffic conditions.

These findings indicate that intelligent traffic signal control can improve emergency response efficiency and reduce delays at intersections. The project demonstrates the potential of smart city technologies to support safer and more effective transportation systems for emergency services.

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Biography

Arda Efe Solak is a middle school student who is interested in science and technology. He is currently attending Private Beştepe Middle School on a scholarship. He consistently achieves scores above 95 in mathematics and science examinations and is ranked within the top 1–5% of students overall. He especially enjoys working on engineering, technological design, AI-supported systems, and smart city technologies. In this project, he worked on a navigation-integrated smart traffic light system that can help emergency vehicles move faster in city traffic. He researched how modern technologies such as GPS, sensors, smart traffic management, and AI-supported transportation systems can be used to help save human lives. He values teamwork, research, and learning new technologies. By developing STEM projects, he aims to improve his engineering skills and create innovative ideas that can benefit society. He also enjoys presenting his ideas and receiving feedback from experts. In the future, he would like to become an engineer/scientist who develops beneficial technologies that make human life safer, faster, and more sustainable. He wants to produce environmentally friendly ideas that help protect the world.