SIMULATION OF AN IOT-BASED SMART TRAFFIC SYSTEM TO REDUCE EMERGENCY RESPONSE DELAYS FOR AMBULANCES

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ABSTRACT/OVERVIEW

Title:	**SIMULATION OF AN IOT-BASED SMART TRAFFIC SYSTEM TO REDUCE EMERGENCY RESPONSE DELAYS**
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CHAPTER 1

INTRODUCTION

In emergency situations, every second counts. Whether it is a medical crisis requiring an ambulance, a fire that demands immediate intervention, or any other critical incident, the timely arrival of emergency response teams can make the difference between life and death. Unfortunately, in urban areas, particularly in highly congested cities, traffic has become a significant obstacle to efficient emergency response.

Ambulances transporting patients in critical condition often face delays due to traffic jams, prolonging the time it takes to reach hospitals. This delay increases the risk of complications and mortality, particularly in cases like heart attacks, strokes, or severe trauma, where immediate medical attention is crucial.

As traffic congestion continues to escalate, the limitations of existing traffic management systems become increasingly apparent. Many of these systems are not equipped to accommodate the urgent needs of emergency vehicles, often treating all traffic equally, which exacerbates delays during critical moments. This growing disconnect between traffic flow and emergency response requirements underscores the necessity for innovative solutions that can prioritize and expedite access for emergency vehicles in real time.

The current traffic management systems in the Philippines and other developing nations are often unequipped to prioritize emergency vehicles, compounding the problem further. This issue highlights the need for innovative solutions that can dynamically adapt to traffic conditions and provide emergency vehicles with prioritized access through congested roads. Addressing this problem through advanced technologies like the Internet of Things (IoT) has the potential to significantly enhance emergency response times, reducing delays and improving overall outcomes for those in critical need of assistance.

This study aims to simulate an IoT-based smart traffic management system designed to prioritize emergency vehicles like ambulances and firetrucks at intersections, addressing the urgent need to mitigate response delays caused by traffic congestion.

BACKGROUND OF THE STUDY

Emergency medical services (EMS) play a critical role in saving lives, with response time being a key factor in determining patient outcomes. Traffic congestion in urban areas frequently hinders the swift movement of ambulances, leading to delays that can negatively affect patient health and survival rates. The integration of Internet of Things (IoT) technologies into traffic management systems has emerged as a promising solution to mitigate these challenges and improve emergency response efficiency.

International studies underscore the efficacy of IoT-based smart traffic systems in enhancing emergency response times. For instance, a study published in *Sensors* demonstrates the use of unmanned aerial vehicles (UAVs) in coordination with traffic controllers to guide emergency vehicles along optimized paths, significantly reducing response times, though constraints such as UAV battery life and weather conditions are noted (An Intelligent IoT-Based Traffic Light Management System for Emergency Vehicles, 2023). Similarly, research on a cyber-physical system for smart traffic light control highlights how IoT-based traffic systems can optimize ambulance routes and prioritize traffic signals, contributing to substantial improvements in emergency response efficiency (Cyber-Physical System for Smart Traffic Light Control, 2023).

In the Philippine context, traffic congestion poses a significant obstacle to EMS, particularly in densely populated areas like Metro Manila. Studies highlight the potential of real-time data and intelligent traffic light control in enhancing ambulance response times and improving patient outcomes. The integration of IoT in traffic management is increasingly recognized as a viable approach to addressing urban congestion challenges.

This study aims to simulate an IoT-based smart traffic system tailored for urban areas in the Philippines, assessing its potential impact on reducing ambulance delays caused by traffic congestion.

STATEMENT OF THE PROBLEM

In urban environments, emergency vehicles such as ambulances often encounter significant delays at traffic signals, which can critically impact response times and jeopardize the safety and well-being of individuals in urgent need of assistance. The inability to prioritize emergency vehicles at intersections leads to prolonged arrival times, increasing the risk of adverse outcomes for patients and victims. To address these pressing challenges, this study proposes the development of an IoT device that can detect upcoming traffic lights along emergency routes and communicate with them to facilitate the swift passage of emergency vehicles. By implementing an effective signaling system, the project aims to ensure that all road users, including pedestrians and drivers, yield to emergency vehicles, thereby minimizing delays at critical moments. This study aims to answer the following questions:

1. *How can an IoT device be effectively designed to detect and communicate with traffic lights within a substantial radius to prioritize the passage of emergency vehicles in a simulation?*
2. *What signaling mechanisms can be implemented to ensure that all road users, including pedestrians and drivers, yield to emergency vehicles in a timely manner?*
3. *What are the impacts of implementing this IoT-based traffic management solution on emergency response times and overall public safety?*

OBJECTIVES OF THE STUDY

The successful implementation of an IoT-based traffic management system hinges on several key objectives that align with the overarching goal of improving emergency response times. This study aims to create a comprehensive solution that not only facilitates the swift passage of emergency vehicles but also promotes awareness among all road users. By focusing on the development of an innovative IoT device and an effective signaling system, the study seeks to address the critical challenges faced by emergency services in congested urban environments. Achieving these objectives will contribute to a more efficient traffic flow during emergencies and ultimately enhance public safety. The objectives of this study are as follows:

1. *To develop an IoT device capable of detecting traffic lights along potential emergency routes and communicating with them to facilitate the rapid transit of emergency vehicles.*
2. *To design an effective simulation signaling system that alerts both pedestrians and motorists to yield to approaching emergency vehicles, thereby minimizing delays at intersections.*
3. *To assess the potential improvements in emergency response times and public safety resulting from the deployment of the IoT device and signaling system in real-world scenarios.*

SCOPES AND LIMITATIONS

Scope

1. **Focus on Emergency Vehicles**: The study will target emergency vehicles, specifically ambulances, examining how the proposed IoT device and signaling system can prioritize their passage through traffic.
2. **Urban Environment**: The research will be conducted in urban settings, particularly in Imus, Cavite, where traffic congestion is a prevalent issue affecting emergency response times.
3. **IoT Device Development:** The study will include the design and development of a functional prototype of the IoT device that detects traffic lights and communicates with them to facilitate emergency vehicle transit.
4. **Signaling System Implementation**: The study will explore the design of an effective signaling system to alert road users to yield to emergency vehicles, ensuring safety and compliance at intersections.

Limitations

1. **Geographical Constraints:** The research will be limited to specific locations in Imus, Cavite, which may affect the generalizability of the findings to other urban areas with different traffic dynamics.
2. **Technological Feasibility:** The implementation of the IoT device and signaling system may face challenges related to technological limitations, such as integration with existing traffic infrastructure and the reliability of communication between devices.
3. **User Compliance:** The effectiveness of the signaling system relies heavily on the compliance of pedestrians and motorists. The study cannot control or predict user behavior in real-world scenarios, which may affect outcomes.

4. **Timeframe for Evaluation**: The study will assess the effectiveness of the IoT solution over a limited timeframe, which may not capture long-term impacts on emergency response times and public safety. Further longitudinal studies may be necessary to evaluate sustained effectiveness.

DEFINITION OF TERMS

Emergency Situations

Critical incidents requiring immediate response, such as medical emergencies or fires.

Emergency Response Teams

Personnel trained to provide urgent assistance in crises, including paramedics and firefighters.

Traffic Congestion

Excessive vehicles on the road causing delays and slow movement.

Traffic Management Systems

Frameworks for monitoring and controlling vehicular movement.

IoT Device

A smart device that collects and transmits data to enhance connectivity and communication with other devices.

Signaling System

Mechanisms designed to communicate the urgency of emergency vehicles to road users.

Prioritized Access

Immediate clearance for emergency vehicles at intersections.

Simulation

A virtual model used to study the performance of a proposed system.

Response Times

The duration taken for emergency teams to reach an incident after notification.

Public Safety

The well-being and protection of the general populace during emergencies.

Prolonged Arrival Times

Extended periods for emergency vehicles to reach their destinations due to obstacles, such as traffic.

Compliance

The degree to which road users adhere to traffic signals and regulations, especially regarding yielding to emergency vehicles.

Urban Environment

Areas characterized by high population density and significant infrastructure, such as cities and towns.

Traffic Signals

Devices that control vehicular and pedestrian traffic at intersections using lights or signs.

Prototype

An initial model of the IoT device designed for testing and evaluation before full-scale production.

Real-time Data

Information that is collected and processed immediately as events occur, allowing for prompt decision-making.

Crisis Management

The process of preparing for, responding to, and recovering from emergency situations.

Road Users

Individuals who use roadways, including drivers, pedestrians, cyclists, and motorcyclists.

Traffic Flow

The movement of vehicles along roadways, which can be affected by congestion and other factors.

Dynamic Adaptation

The ability of a system to adjust and respond to changing conditions in real-time.

THEORETICAL FRAMEWORK

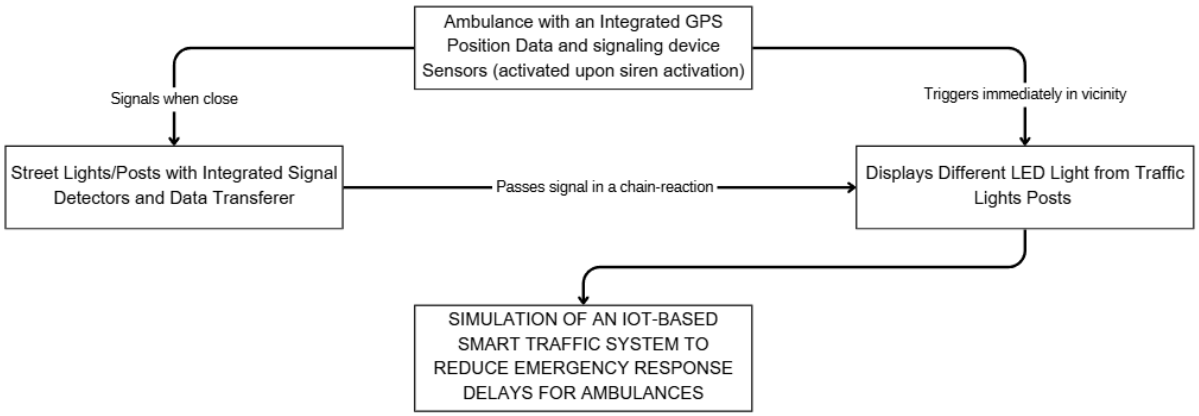

Figure 1: This diagram illustrates the conceptual mechanism and data flow of the IOT-based traffic system as an approach to reduce emergency response delays for ambulances simulation.

CHAPTER II

Review of Related Literatures / Studies Foreign

Ambulance Offload Delays and Patient Outcomes: Dawson et al. (2022) conducted a population-based observational cohort study examining the impact of ambulance offload times on patient outcomes for adults presenting with non-traumatic chest pain in Victorian emergency departments (EDs). The study analyzed data from 213,544 patients between January 2015 and June 2019, revealing that prolonged offload times were associated with increased 30-day risks of death and ambulance re-attendance. Specifically, patients experiencing offload times exceeding 28 minutes had a higher adjusted mortality rate (1.57%) compared to those with offload times under 17 minutes (1.29%). The research highlights the urgent need to improve ambulance-to-ED transfer processes to mitigate overcrowding and enhance patient outcomes. This study underscores the broader implications of systemic delays in emergency healthcare services, emphasizing the critical importance of timely interventions in reducing mortality and repeat ambulance utilization.

Emergency Response Delays in Mass Casualty Incidents: Alruqi et al. (2023) conducted a systematic review investigating pre-hospital times (PHTs) in trauma-related mass casualty incidents (MCIs) and identifying factors contributing to delays in triaged patient transport. The review included 12 studies, comprising six observational cohort studies and six case reports, which reported PHTs ranging from a median of 35 minutes to over 8 hours. Key factors associated with prolonged PHTs included challenging incident locations, safety concerns at the scene, and ineffective decision-making during triage. Interestingly, the number of casualties did not consistently impact PHTs. The findings highlight that delays exceeding 2 hours were common, suggesting that future MCI response strategies should prioritize improved triage decision-making and operational planning for challenging environments to reduce delays and improve patient outcomes.

Lucchese (2023) conducted a study to investigate the critical relationship between ambulance response time (RT) and health outcomes for cardiovascular patients. The research emphasizes the paramount importance of timely medical responsiveness in determining patient survival and recovery. By analyzing data on emergency call times, ambulance arrival, and patient admission to hospitals, the study identifies a direct correlation between delays in RT and adverse patient outcomes. Key findings reveal that a one-minute increase in RT raises the probability of patients being in critical condition by 1.6 percentage points upon ambulance arrival and increases the mortality rate by 0.7 percentage points upon hospital admission. Additionally, the study quantifies the economic impact of reducing RT, highlighting that decreasing the average RT in Liguria by one minute could save approximately 7.8 million euros annually. These results underscore the value of investing in increased ambulance availability and advanced traffic systems, reinforcing the importance of integrating IoT-based smart traffic solutions to optimize emergency response times and improve patient outcomes.

Alrawashdeh et al. (2021) conducted a retrospective observational study examining the relationship between emergency medical service (EMS) delay times and clinical outcomes in patients with ST-elevation myocardial infarction (STEMI) undergoing primary percutaneous coronary intervention (PPCI). Analyzing data from 2,976 STEMI patients who presented to EMS between January 2014 and December 2017, the study found that longer EMS delay times were significantly associated with higher 30-day mortality rates. Specifically, patients who died had a median EMS delay time of 74 minutes, compared to 59 minutes for those who survived ($p < 0.001$). The research indicated that for every 30-minute increase in EMS delay, there was an adjusted odds ratio of 1.20 for mortality, highlighting the critical importance of timely EMS responses, especially for complicated cases such as cardiogenic shock or cardiac arrest. The study concluded that reducing EMS delay times is essential for improving outcomes and ensuring timely reperfusion in STEMI patients.

Adeyemi et al. (2023) conducted a retrospective cohort study analyzing data from the National Trauma Data Bank, focusing on patients aged 65 years and older who sustained fall injuries and were transferred to U.S. trauma centers. The study aimed to estimate the relationship between Emergency Medical Services (EMS) response times and fatal fall injuries, considering factors such as age, sex, race/ethnicity, and chronic conditions like COPD and diabetes. The findings indicated that a one-minute delay in EMS response time increased the odds of fatal fall injury by 1%. Notably, older adults experiencing response times exceeding the standard nine-minute benchmark had significantly higher odds of fatal injuries. The study highlights the critical importance of timely EMS response in preventing fatalities among older adults suffering from falls.

Review of Related Literatures / Studies Local

Nuevas et al. (2024) conducted a study investigating the development and deployment of a mobile and web application for Android devices, utilizing GPS technology to enhance emergency response systems in Abuyog, Leyte, Philippines. The research aimed to address challenges such as delayed emergency response, lack of portability, and inefficient information delivery during critical situations. By leveraging mobile device capabilities and GPS integration, the system enabled users to quickly report incidents, pinpoint locations, and notify relevant authorities. Designed to be user-friendly, cost-effective, and energy-efficient, the application demonstrated significant effectiveness in reducing response times and improving emergency management processes. The iterative development process incorporated client feedback and iterative testing, resulting in a system with a high acceptance rate. Evaluation by thirty end-users yielded an overall grand mean score of 4.77, reflecting strong acceptance and high-quality performance of the system.

Cahatol et al. (2019) conducted a mixed methods study to identify and analyze factors influencing the emergency response time of vehicles in 16 barangays in Quezon City, Philippines. Data were collected from trip records spanning August 2018 to February 2019, and both quantitative and qualitative factors were considered. Key variables included radial distance, traffic volume, rainfall, and specificity of location. The study found that traffic volume and radial distance significantly affected emergency response times, with radial distance being a notable predictor. Qualitative insights, gathered through semi-structured interviews with emergency personnel, revealed organizational and psychological factors that impact response efficiency. These included perceived organizational support, job perceptions, and motivations, alongside the severity of hypothetical patient conditions.The study concluded that addressing traffic congestion and improving emergency response infrastructure—such as increasing vehicle availability in larger barangays—could mitigate delays. Recommendations included enhanced government protocols for training and

supporting first responders, stricter enforcement of traffic laws favoring ambulances, and adoption of GPS technology for more precise data collection and analysis.

Lacasandile et al. (2022) conducted a study presenting the development and deployment of a mobile- and web-based system named E-Saklolo, designed to respond to various emergency situations, including medical, fire, rescue, and police incidents within communities in the Philippines. The system leverages modern ICT solutions to address the challenges posed by disasters, which often result in widespread human, material, and economic losses, with the Philippines incurring an estimated $23 billion in disaster-related damages. Deployed in 2019, E-Saklolo demonstrated its effectiveness by increasing the number of resolved emergency cases, thereby improving emergency response efficiency and reducing casualties. Future enhancements to the system aim to integrate dashboards and analytics to support administrators in generating relevant reports and data for better decision-making.

Lagman et al. (2022) developed an emergency response application using Dijkstra’s method to identify the shortest paths for first responders to reach disaster victims. Given the Philippines' vulnerability to frequent and unexpected disasters, the study emphasizes the critical role of minimizing response times in saving lives, especially during the crucial initial hours after an incident. The researchers employed Agile methodology in the system's development, ensuring an iterative and user-centered approach. Evaluated using the ISO 9126 tool, the system received a rating of 4.52 out of 5, interpreted as "Very Acceptable," highlighting its readiness for deployment. The study underscores the potential of the application to enhance the efficiency of emergency response and improve survival outcomes in disaster situations.

Salanga et al. (2023) examined the challenges faced by barangay first responders in emergency response, focusing on coordination and communication, training, and information

and education campaigns. The study revealed that first responders encountered significant difficulties in coordination and communication, particularly in clustering barangays to prevent duplication of responses and wastage of government resources. Moderate challenges were identified in training and education campaigns, including the conduct of regular training sessions and the use of independent telecommunication systems supported by alternative communication links, such as microwave and satellite systems. Older, male respondents, and those with shorter lengths of service reported higher levels of difficulty across all areas compared to younger, female, and more experienced counterparts. While no significant differences were observed in overall difficulty levels based on age, sex, or service length, individual responses highlighted coordination and communication issues as the most problematic. The findings underscore the need for improved strategies to address these challenges, particularly in barangay-level emergency response coordination.

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