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Development of a prioritized traffic light control system for emergency vehicles

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ABSTRACT

This research presents a model for an adaptive traffic signal control system aimed at improving urban traffic regulation. It dynamically adjusts signal timing based on vehicle volume at intersections, prioritizing emergency vehicles by allowing them immediate passage. Utilizing Arduino coding, the system controls traffic light intensity according to the traffic flow, enhancing road safety and efficiency. This innovative approach not only facilitates faster clearance for emergency services without human intervention but also reduces congestion and accident rates. This research creates a model for a prioritized traffic signal control system. When the vehicular volume at the intersection varies, the signal time alters autonomously. It identifies the ambulance/emergency vehicles and allows the green light for emergency vehicles like ambulances, and fire engines. This approach may be used to detect traffic accidents and infractions of automobile spiral motions. When erected on the road, the entire system allows for quick traffic clearing for rescue vehicles without requiring a policeman. The system's design eliminates the need for sensors or radio frequency identification (RFID) tags, simplifying traffic management. Simulations validate that emergency vehicle travel time is significantly reduced, proving the system's effectiveness in streamlining urban traffic flows.

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1. INTRODUCTION

The urban environment hums with the pulse of mobility. Vehicles swirl across a patchwork of streets, their flow governed by the traffic signal, the quiet conductor. However, in today's modern city, when time is valuable and fuel is short, a one-size-fits-all strategy for traffic regulation is no longer adequate. Enter the prioritized traffic light control system model (PTLCSM), a game-changing idea that has the potential to rethink the urban symphony of movement. Traffic signal systems are used to govern more than two vehicle passing channels or when pedestrians cross a road [1]–[3]. In the case of a four-way lane, it is also utilized when two pathways intersect. Traffic congestion is regarded as one of the most serious issues in metropolitan areas [4].

Traffic congestion is predicted to worsen as a result of the rising number of modes of transportation and the existing poor condition of road infrastructure. Furthermore, numerous studies and statistics have been created in developing nations proving that the majority of road fatalities are caused by limited roads and the harmful expansion in transportation methods. A system with flexibility capable of managing traffic density is necessary for big traffic systems. The fundamental disadvantage of a generalized traffic control system is the difficulty in detecting high-priority events and emergency scenarios [5]. This emphasizes the necessity for a smart traffic management system that can handle all scenarios and make judgments autonomously.

A traffic management system's goal is to manage vehicle movement within an intersection and to avoid collisions or road blockages. The signal lights used for the current traffic systems are notably, red, yellow, and green for stop, get ready, and go accordingly, with each light operating one after another for a specified length of time in most developing nations. The delay characteristics that affect traffic load include time, day, season, weather, and unforeseeable events like as accidents or construction operations. Congestion can be alleviated by constructing new roadways [6]. The only disadvantage is that the environs get more crowded. Instead of building additional facilities twice, it is necessary to modify the traffic system. These issues can be remedied by continually monitoring and modifying traffic signal timings based on real traffic demand, which image detection systems can do.

The major goal of this study is to examine traffic lights and more congested areas and to provide precedence to emergency vehicles and ambulances at traffic intersections. This requires just minor physical alterations to the crossing and delivers the quickest clearing to vehicle/pedestrian traffic in all directions. This, in turn, offers a variable traffic light system that ensures variations in traffic density while also reducing traffic warden stress and accidents. Traffic congestion causes no problems in the event of an emergency and reduces fatalities [7]. As a result, traffic may be controlled without the need for a sergeant, and the suggested solution saves people's lives and valuable time.

Previous studies and practical applications have established the potential of real-time, traffic-responsive signal optimization strategies to minimize driver pauses and delays at particular signalized junctions [8]. As a result, it is realistically critical to build, check, and validate simple yet powerful models that aid in the design and improvement of public transit security and effectiveness, while rescue vehicles are ignored. Ambulances, police cars, fire engines, and other emergency vehicles that become caught in traffic and are delayed in reaching their destination can result in the loss of property and valued lives [9], [10]. Rising car number not only enhances the time taken for rescue vehicles but also improves their chances of being involved in fatalities [11]–[13]. The emergency car going into a junction at high speed on a red light endangers traffic on other roads and can cause accidents. Based on the present issue in this section, it is clear that a sophisticated traffic management system is required for efficient control of both typical and emergency automobiles [14]–[16].

This paper proposes a method for scheduling emergency vehicles in gridlock. The technology integrates visual detecting techniques for measuring the distance that exists between the rescue car and an intersection, automobile counting, and time-sensitive warning transmission within the sensor networks. To recognize emergency vehicles, the sensors capture siren signals and transfer them to the measuring controller (Arduino UNO). And passes them over to the frequency measurement controller. The emergency vehicle's siren wavelengths are detected by the control device. The control unit estimates the average of observed wavelengths after measuring the frequencies of siren sounds. If the frequency is between yelp and wail, the frequency measurement controller sends an alert signal to the traffic signal controller (Arduino Mega). On receipt of approaching emergency vehicle information, the traffic signal controller stops the preset sequence and light length algorithm and conducts the emergency vehicle dispatching algorithm. The suggested algorithm is executed by the controller, and its judgment is sent to traffic lights. The system resumes regular functioning following the passing of an emergency vehicle, and we describe distance measuring techniques, vehicle counting approaches, a distance-based emergency vehicle dispatching mechanism, and the simulation environment.

The PTLCSM goes beyond the constraints of typical red, yellow, and green. It analyzes real-time data from a variety of sources, including cameras, sensors embedded in the pavement, and GPS-equipped automobiles. This data includes information such as traffic density, vehicle type, proximity to emergency vehicles, and even environmental parameters such as weather conditions. With this real-time knowledge, the PTLCSM improves traffic signal timing and sequencing on an intersection-by-intersection basis.

The study's benefit is that it gives a novel method for calculating the distance between the emergency vehicle and the junction. The method will allow for the examination of an aimed at creating a create a framework for a frequency measuring controller to identify emergency cars. A self-organized traffic control method that aids in the functioning of emergency response vehicles; allows emergency vehicles to travel through traffic. A technique for resolving junction-ensuring disputes and implementing a priority plan for prioritizing emergency vehicles at intersections.

The advantages of the PTLCSM go much beyond mere convenience. The technology minimizes fuel consumption and emissions by minimizing congestion and improving traffic flow, resulting in cleaner air and a healthier environment. It shortens emergency response times, potentially saving lives in life-threatening circumstances. Furthermore, it improves the efficiency of public transportation, making buses and trams a more competitive option and contributing to a more sustainable urban ecology. The remainder of this study is structured into five sections; section two discusses the literature review of the related work, section three discusses the methodology used for the prioritized traffic control model, section four describes the results obtained from the simulation, and section five concludes the study.

Essien and Uloko [17] entailed developing a method to reduce the likelihood of accidents prevalent at traffic signal junctions, where vehicles frequently need to swerve to make space for emergency vehicles following a predetermined path. The study was successful in analyzing, simulating, and implementing wireless communication systems for traffic light management. The realized model uses radio frequency identification (RFID) communication, operates in concert with the sequential mode of signals to change the traffic light series, and restores the traffic signals to their original sequence after the emergency vehicle has passed through the intersections. The system made use of a RFID sensor and a reduced instruction set computing (RISC) architecture microcontroller to simplify the operation of a 3-way intersection traffic light and to give rescue vehicles priority.

Mohamed and Radwan [18] provide a unique traffic light control (TLC) technology for different traffic scenarios that is responsive to current traffic conditions at a crossroads and prioritizes essential cars above normal traffic. The suggested method allows for several degrees of priority among priority vehicles and efficiently arranges traffic signals at a junction so that other ordinary traffic is not disrupted. The study does not service priority vehicles such as buses or emergency vehicles (ambulances and fire engines). This work investigates the traffic patterns in less-disciplined, diverse traffic (two-three-four-wheeler cars), which is common in most developing nations. According to the simulation findings, the suggested method can tolerate a 20% mistake in the passenger car unit count without affecting performance. Furthermore, this study indicates that the requisite precision in traffic information can be handled in real-time utilizing the available microcontrollers.

Bisht *et al.* [19], the investigation strategy has placed a high focus on planning, analyzing, and reporting outcomes. According to the study's findings, a specialized design that monitors traffic on roads and gives intelligent alternatives has yet to be established. The standard design method lacks intelligent performance, adjustable time frames, learning capabilities, emergency prioritization administration, and dynamic duration sequences. While the adaptive self-organization strategy disregarded learning skills. However, the vast majority of cleverly planned experiments lacked cognitive stress responses and feedback capabilities.

Ariffin *et al.* [20] offer an intelligent system that dynamically modifies the cycle length for each lane at a junction based on traffic density and gives different types of emergency vehicles access to the crossroads by assigning varying priority. The system is divided into three modules: automation of traffic lights, emergency RFID, and the internet. Using ultrasonic sensors, the traffic light regulation modules detect motorist density and provide an evolving set of cycle lengths according to the specific lane density situation. Emergency RFIDs are fitted on several sorts of emergency vehicles based on predetermined priority weights. The internet module enables authorized staff to manage the dynamic traffic signal system in real time.

Kumar *et al.* [21] use a dynamic and intelligent traffic light control system (DITLCS) that operates in three forms: Fair mode (FM), priority mode (PM), and emergency mode (EM), in which all vehicles have equal priority, motorcycles of various categorizations have different degrees of importance, and medical vehicles have the highest priority. A complex reinforcement learning approach is also demonstrated to toggle traffic lights in distinct phases (red, green, and yellow), and a fuzzy inference system is demonstrated to pick one mode between the three options (FM, PM, and EM) based on traffic data. The simulation results demonstrate DITLCS's efficiency in comparison to other state-of-the-art algorithms on a variety of performance metrics.

According to Peter *et al.* [22], an attempt is made in study to enhance the Kaduna Refinery Junction's (KRJ) current programmed stationary road traffic signal management system. The KRJ is the main road connecting the southern region of the state to Kaduna's major town. During the workday, vehicles from other parts of the country, public and private servants, students, merchants, and others traveling to other areas of the country via the state's southern half converge at the KRJ. An economical model of the fuzzy logic (FL) method is created for the most effective planning of TLC systems using TraCI4MATLAB and simulation of urban mobility (SUMO). The average improvement over the previous result was 2.74%. When emergency vehicles were prioritized, there was a 66.79% improvement over static phase scheduling. This demonstrates that FL can be useful in traffic control systems.

Li *et al.* [23] planned effort, which is based on automobile priority, intends to provide a smart traffic signal system to which the high priority vehicles (HPV) may request being loaded at a crossroads. Depending on the greatest priority, the system would change the traffic signal green to clear the road segment (RS) and save HPV travel time. The system is evaluated using the Python traffic control interface (TraCI) and SUMO. The findings demonstrate the efficiency of the intelligent traffic signal system. In the future, it may have important theoretical as well as practical utility for intelligent transportation systems (ITS).

Traffic lights are intended to keep cities moving smoothly [24]. The existing traffic system has been in place for some years [25]-[29]. As the number of cars on the road increases, this method is failing to address traffic congestion issues, particularly at junctions. HPV becomes caught in traffic as a result of traffic congestion, causing delays in their services. HPVs, such the ambulances and fire trucks, must respond to a variety of incidents. HPV must arrive on time. There is a need for a system that provides a conduit for HPV to travel as soon as feasible. The suggested work takes a prioritized approach. It seeks to provide a user-interactive HPV system in which an HPV driver may submit requests to the system and the system reacts intelligently. At a junction, the priority of RS is determined, and the traffic signal turns green for the RS with the highest priority. The method was evaluated on SUMO and yielded positive results, saving more than 50% of the time across all traffic concentrations (low, moderate, and high).

2. METHOD

The process employed in this research includes managing traffic center performance, distance measuring techniques, and a distance-based rescue vehicle, determining the position of the emergency car, and methods for emergency vehicle identification based on siren sounds. The amount of time it takes to get to the next set of intersections. The traffic signal will revert to its usual sequence after the emergency vehicle has passed. For the setting up of this system, an ARDINUO UNO was employed.

2.1. Traffic detection

The support model, like other traffic-responsive flag management systems, determines signal-switching choices based mainly on expected vehicle coming data. The data is acquired via traffic detectors strategically placed along the road leading to the controlled junction. The concept allows for the deployment of one or more traffic detectors along junction approaches at any point. Support records the detecting time and kind of car whenever the car travels over a sensor. The simulator is entity-oriented and takes into account three object types: cars, segments, and vehicle actions. The total amount of segments and vehicle operations are set by the user. Vehicles are created automatically during simulation based on user-defined flow parameters (for example, statistical distributions of inter-arrival durations, platoon features, and arrival lists). The simulator can simulate the effects that transit vehicles have on other cars when they stop on the correct amount of road to board and release people.

2.2. Rule-based signal-switching decision process

The support paradigm decides on signal flipping via a heuristic rule-based signal optimization approach. The technique is based on the knowledge that signal changes often occur after the realization of specified discrete occurrences, such as when a line of cars reaches a given size when a queue dissipates, or when an arriving transit vehicle is detected. The approach allows the support model to greatly minimize the number of alternative switching permutations that must be investigated to identify a near-optimum solution by discarding those events that have no significance for signal functioning. The model particularly analyzes the following reactions to significant traffic events that occur on a particular junction strategy:

– Step 1: If there is an n-vehicle stop line queue that is not being offered, begin servicing the queue as soon as feasible. If the stop line queue reaches a user-defined length, turn the signal display green.
– Step 2: Keep the present green signal indicator in a direction where the upstream queue's reach exceeds a user-defined position.
– Step 3: If a backlog on one of the method's user-defined main exit connections impends to leak back over the junction, turn the light red.
– Step 4: When a group of n or more cars approach the junction, turn the signal show to green at a moment that allows the platoon to pass the junction without being influenced by vehicles halted at the stop line.
– Step 5: If a vehicle line is being served, continue to serve the queue.
– Step 6: If you are serving a platoon of vehicles, keep doing so.
– Step 7: As a transit vehicle approaches its transit stop, turn the signal show to green at a moment that allows the vehicle to continue up to its putting position undisturbed.
– Step 8: As a transit vehicle approaches the stop line, turn the signal display to green at a moment when the vehicle can cross the roadway without stopping.
– Step 9: To account for the reality that not all traffic occurrences are equal in importance, each event is given a priority or weighting.

– Step 10: By the detection of any priority occurrence during the period during which traffic arrives, the signal optimization method provides requests for either a green or a red signal indication on certain approaches at specified times.

2.3. Multi-objective optimization process

While the support approach can identify the relative significance of multiple traffic events by using prioritized listings of incidents, it is frequently impossible to know which event ought to receive the greatest priority ahead of time. The user can choose the relative weights for pauses, delays, and travel time (kd, ks, kTT). Travel time is not taken into account in any of the assessments in this article (i.e. kTT=0). The operation additionally incorporates a terminal cost component that projections the delays incurred by every car left in the queue outside the end of the choice horizon under the presumption that no additional cars join the queue beyond the end of the choice horizon and that queue expelled happens at the greatest rate. The terminal cost is used to overcome a bias that might cause the signal optimization procedure to pick signal-switching options that produce a low cost in the short term but a high cost later on.

2.4. Architectural design of the system

The system architecture of the proposed system shows how the system behaves with the aid of a simple design. As shown in Figure 1, the traffic system must prioritize emergency circumstances. The administrator logins to the laptop and connects to the Arduino board in which all the wiring of all four lanes is connected to the Arduino board and also to the ground on the Arduino board, then the traffic light for the four-lane works. On the preemption of the ambulance, it triggers the light and changes to green for the passage of the ambulance and returns to the normal traffic flow.

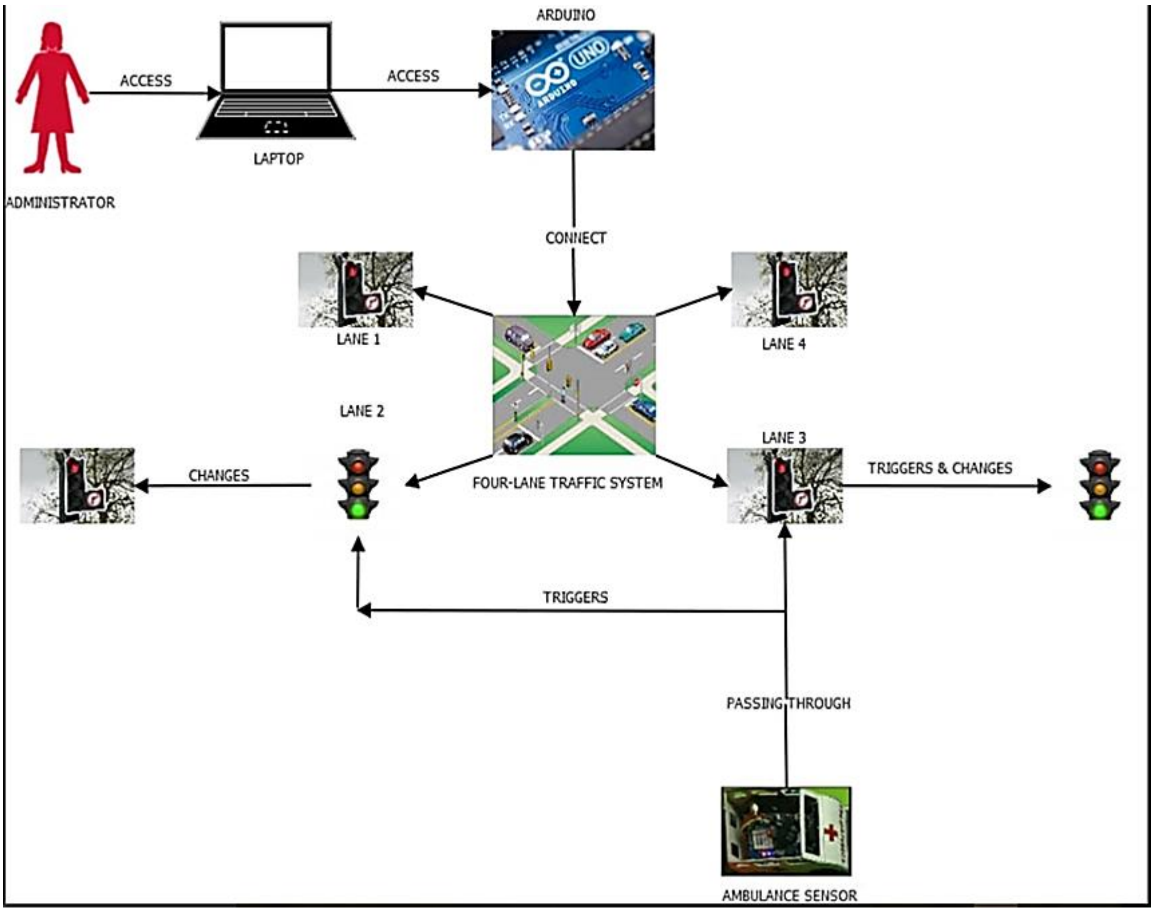

Figure 1. Architectural diagram of a prioritized traffic flow

The algorithm determines which route should be granted a green light based on queue length, vehicle speed, vehicle acceleration, and car distances from the junction. It defines the sequence in which the various green stages ought to be completed and how long they should last. The procedure is then repeated when these steps have been completed. The sequence of phases is determined by the length of each queue approaching the intersection, with a bigger queue receiving more priority than a smaller one, and the ambulances which approach the road first. Furthermore, the algorithm utilizes the journey duration of each lane active in the stage is determined by the vehicle velocity and distance to the junction. The longest traversing time is then picked as the stage time frame, as long as it is less than a preset optimum green time of 60 seconds. Three seconds is the yellow time and red is set to 90 seconds.

3. RESULTS AND DISCUSSION

The model for the prioritized TLC system is designed using a microcontroller and an integrated circuit i.e. Arduino, a breadboard, jumper wires, a motorcar, LED lights, and Wi-Fi module (T). This system is employed because of its efficacy, speed, and efficiency. Its functionality and method are simple and easy to use.

3.1. Testing and evaluation of the system

This system was linked using jumper cables, and each element of the connection functioned well. The functioning of the system was shown on a tiny carved traffic light board, and its outcomes were carefully tested against established circumstances, and at any positive of a set conditions something is triggered. Figure 2 shows the connection of LED lights to the breadboard and jumper wires connected to the breadboard all connected to the Arduino. The jumper wires are connected respectively to the numbers each on the Arduino, each lane is connected to 3 spaces each on the Arduino board. The connection of the Arduino board with jumper wires to the respective 4 lanes of the traffic order and connecting the Arduino to the laptop where the code is written, the wires are connected to the numbers on the Arduino respectively, and a wire is connected to the ground on the Arduino board as shown in Figure 3.

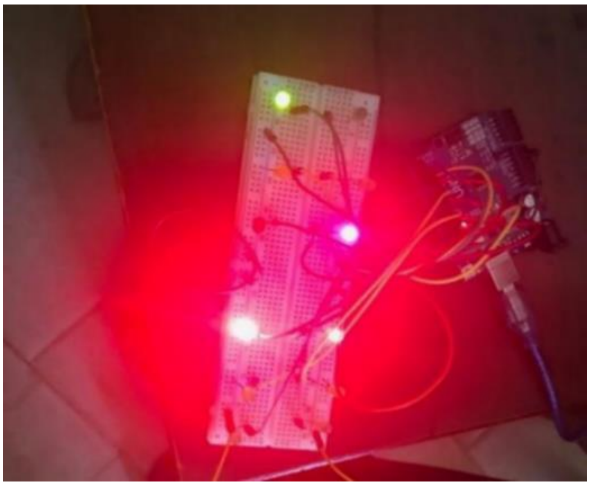

Figure 2. Traffic control implementation board

Figure 3. Traffic control implementation board

The wires are already connected; the Arduino board is already connected to the system also; it further shows the light for the four lanes; the first lane is on light, the second lane is on red light, the third lane is on yellow light about to change to greenlight, then the last lane is on red light as shown in Figure 4. The wires are already connected; the Arduino board is already connected to the system also; It further shows the light for the four lanes; The first lane is on a yellow light about to change to a red light, and the second lane is on a red light, the third lane is on red light about to change to greenlight, then the last lane is on yellow light about to change to greenlight as shown in Figure 5. Figure 6 shows the lights; The wires already connected; Arduino board already connected to the system also. It further shows when the ambulance is approaching a particular lane which is on red; when it receives the signal that the ambulance is approaching from the code it changes to green light for the passage of the ambulance and goes back to the normal position.

Figure 4. Traffic control board simulation with prioritized model

Figure 5. The traffic light board shows a yellow light on the first lane

Figure 6. Traffic light signaling to the ambulance approaching

3.2. Statistical analysis

One sample t-test was conducted to determine the average distance at which the ambulance is detected. Results show that t=-1, df=14, p-value=0.3343 with a 95% confidence interval (298.9517, 300.3816) for the mean. Since the p-value=0.3343 is greater than the significance level, 0.05, it was observed that the average distance at which an ambulance is detected is 300 meters. For the accuracy of the normal traffic flow, a one-sample t-test was conducted. Accuracy of red traffic lights, there was no need to conduct the t-test since all the times recorded were 90 seconds. This implies that the red traffic light is accurate in its time delay.

For accuracy of the yellow light for the normal traffic flow: results show that t=-1.8708, df=14, p-value=0.08242 with a 95% confidence interval (2.570713, 3.029287) for the mean. Since p-value=0.08242 is greater than the significance level, 0.05, we conclude that the yellow light delay is 3 seconds. As such the yellow light delay time is accurate.

For accuracy of the green light for the normal traffic flow: results show that t=1, df=14, p-value=0.3343 with a 95% confidence interval (29.92368, 30.20965) for the mean. Since p-value=0.3343 is greater than the significance level, 0.05, we conclude that the green light delay is 30 seconds. For the green light passage for the ambulance, a one-sample t-test was also conducted. Results show that t=-1.4446, df=14, p-value=0.1706 with a 95% confidence interval (28.01227, 30.38773) for the mean. Since p-value=0.1706 is greater than the significance level, 0.05, we conclude that the green light passage time for the ambulance is 30 seconds.

3.3. Discussion

The creation of a PTLCSM has enormous promise for improving traffic flow, decreasing congestion, and shortening emergency response times. This statistical study sheds light on the model's performance in terms of both regular traffic and ambulance prioritizing. The PTLCSM could be used to create sophisticated systems that utilize advanced technology and algorithms for dynamic traffic signal control prioritizing emergency vehicles like ambulances but also allowing normal vehicular movement. The key components of the PTLCSM are; i) real-time data using sensors: employs a network of traffic sensors and cameras to gather up-to-the-minute records of traffic density, vehicle types, and on-road status; ii) technologies of communication: utilizes vehicle-infrastructure communication (V2I) to detect and prioritize emergency vehicles approaching intersections; and iii) traffic management based on algorithms: incorporates algorithms capable of rapidly changing signal phases depending on actual road conditions and requiring priorities for ambulances and other emergency vehicles to allow them to cross junctions quickly without any problems. The organization PTLCSM guarantees these gains for movements across cities. Including but not limited to; better traffic modulating efficiency and multi-sectoral influencing factors; such as increased safety where quicker clearances are provided for ambulances thus providing good patient results in case of medical emergencies; lowered CO_2 emissions that are attributed to less time spent idling and more fluid driving conditions; less time spent in traffic can lead to lower fuel usage and thus increased productivity at an economical level.

3.4. Key findings

The major findings of this research are as follows:

a. Ambulance detection: the average distance at which ambulances are identified is 300 meters, giving the system enough time to prioritize traffic signals.
b. Normal traffic flow
- The red-light delay is consistently 90 seconds.
- The yellow light delay is 3 seconds.
- The green light delay is precise at 30 seconds.

c. Prioritization of ambulances: the green light passage duration for ambulances is also correct at 30 seconds, guaranteeing a smooth and quick transit.

According to the statistical analysis, the PTLCSM meets its objectives for both regular traffic flow and ambulance prioritizing. The technology recognizes ambulances at a safe distance, prioritizes their passage through green lights, and keeps all traffic lights on time.

3.5. Further considerations

While the study yields encouraging results, it should be noted that it is based on a small sample size. Larger dataset testing might reinforce the conclusions and give more generalizable results. The investigation concentrated on the precision of timing and detection. Future research might look at how the PTLCSM affects other variables including traffic congestion, travel time, and pollutants. The PTLCSM's efficacy may differ based on factors such as traffic density, road layout, and emergency vehicle type. More study is required to understand how the system functions in various settings.

4. CONCLUSION

The PTLCSM has enormous potential to revolutionize traffic management. This statistical study gives positive evidence of its precision and efficacy. However, further study is required to properly comprehend the system's strengths and limits. We can get closer to developing smarter, safer, and more efficient cities for everyone if we continue to enhance and improve the PTLCSM. According to the statistical analysis, the timings of the traffic light system are compatible with the criteria specified for the red, yellow, and green lights, as well as the ambulance detection distance. The fact that the p-values for all tests were larger than 0.05, except for the red light (where the test was not relevant), indicates that there is no substantial evidence that the timings deviate from their respective hypothesized values. In terms of timing accuracy, the research appears to be rigorous and shows a well-functioning traffic signal system.

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