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ALERT: Adaptive Lane Emergency Routing andTraffic Signal Optimization – A Pilot Implementationof a Smart Green Corridor System in SignalizedUrban Intersections

Jerline Sheebha Anni Dhanaraj
Bangalore Technological Institute, Bengaluru, 560035, Karnataka, India
Chin-Shiuh Shieh
National Kaohsiung University of Science and Technology
Mong-Fong Horng
National Kaohsiung University of Science and Technology
prabu Mohandas
prabum@nitc.ac.in
National Institute of Technology Calicut

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ALERT: Adaptive Lane Emergency Routing and Traffic Signal Optimization – A Pilot Implementation of a Smart Green Corridor System in Signalized Urban Intersections

Jerline Sheebha Anni Dhanaraj[1], Chin-Shiuh Shieh[2], Mong-Fong Horng[3], and Prabu Mohandas[4, *]

[1]Research Institute of IoT and Cybersecurity, Department of Electronic Engineering, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan
[1]Department of Computer Science and Engineering, Bangalore Technological Institute, Bengaluru, 560035, Karnataka, India
[2,3]Department of Electronic Engineering, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan
[4]Department of Computer Science and Engineering, National Institute of Technology Calicut, Kozhikode, Kerala
[*]corresponding author: prabum@nitc.ac.in

ABSTRACT

Urban road congestion presents great limitations to the time release of emergency services, usually resulting in delays for more serious medical emergencies. This research proposes an integrated automated Green Corridor system based on geotagging, GPS, and embedded camera-based acknowledgment systems for prioritizing emergency vehicles. Here, Geotags placed 200 meters upstream of intersections enable preemptive signal-timing adjustments, while dual confirmation through the cameras helps to detect ambulances accurately even in adverse weather conditions or heavily congested traffic. The proposed system eliminates human intervention and helps all classes of ambulances without any hardware installations. Real-time alerts, such as patient identification and ETA levels, help hospital preparedness and traffic management coordination. The simulation on SUMO shows a great 65% reduction in response time and better flow dynamics on multijunction roads, for traffic aggregates within networks, and route detours. The scalable, technology-driven solution solves unaddressed issues of emergency traffic management while securing better system reliability and preparedness.

Please note: Abbreviations should be introduced at the first mention in the main text – no abbreviations lists. Suggested structure of main text (not enforced) is provided below.

Introduction

Traffic congestion is a major global problem as it causes the build-up of moving traffic and critically impacts emergency services, such as ambulances, fire trucks, and police vehicles, which play an essential role in ensuring public safety. Such delays in emergency response can be decidedly important, especially in medical crisis."Platinum ten minutes" and "Golden hour" a term in medical field which points out that even a short delay in cases like heart attacks or major road accidents are crucial for patient survival[1]. The mortality rate can be reduced by about 10% if emergency revival is timely. The time in which emergency vehicle expended to accident zone to rescue patient and reach hospital within time is called response time[2]. Vehicle density, defined as the volume of vehicles present or queued on the road, is a critical factor influencing emergency response times. Precise vehicle density information is vital in formulating traffic management plans that maximize the smooth and timely passage of emergency vehicles[3]. As far as India is concerned, the heterogeneity of traffic[4], which includes different road types as well as different vehicle categories, makes it challenging to roll out effective traffic control measures to ease the passage of emergency vehicles.

Conventional traffic systems depend on human adjustment of traffic lights in control rooms to allow ambulances to pass through. This method is susceptible to human error and is not scalable, particularly when there are several emergencies at the same time[5], aside from organ transplant situations. The majority of existing traffic management systems are based on pre-planned routes[6], which restrict their applicability to a particular city[7]. In rural regions or areas with unexpected traffic congestion or roadblocks, this method is not ideal since emergency vehicles might have to take alternative routes. Such time

delays negatively impact the overall efficiency of emergency response times. As per studies, more than 50% of heart attack cases reach hospital late, which can be due to unavailability of ambulances and also because of ambulances stuck in traffic congestion. In Ireland[8] an average of 700 patients died from a traffic accident in an ambulance. To address this, an adaptive and automated solution is essential for larger urban environments with dynamic and unpredictable traffic patterns.

To overcome this in India, the concept of the green corridor was first introduced in Chennai. A green corridor is a dynamic traffic route management in which coordination ensures fewer stops as possible for the emergency vehicle at each junction to reach the destination with a minimal delay at destination. A case occurred where an ambulance successfully transported a heart over a distance of 12 kilometers in under 14 minutes, a journey that would typically take over 45 minutes. Some Indian cities like Chennai have managed to successfully use green corridors for fast organ transportation for transplantation, which helps to reduce the time of transportation between hospitals from 30 to just 11 minutes[9]. A minimum medical response time can lower the probability of death one by third ratio[7].

Although green corridors have proven effective in organ transplants, their current implementation is still manual and limited in scalability. Current systems uses human interventions in control centers to manually adjust traffic signals along navigating ambulance routes[10]. This manual process is prone to human error and lacks the scalability required to accommodate all types of emergency vehicles. Additionally, current green corridor systems are often designed for predefined routes, which restricts flexibility when emergency vehicles need to divert due to unexpected traffic conditions or road obstructions[11]. The manual and difficult nature of these systems results in delays that reduce the overall effectiveness of emergency response services.

Developing an automated green corridor system involves implementing real-time traffic management for ambulances and other emergency vehicles without relying on human intervention[12]. Utilizing technologies such as Geographic Information Systems (GIS)[13], Global Positioning System (GPS), Radio-Frequency Identification (RFID), V2X (Vehicle-to-Everything) communication, and real-time camera-based detection, the system will dynamically optimize traffic signals to facilitate the uninterrupted movement of emergency vehicles. Additionally, it will adapt to route deviations caused by changing traffic conditions, ensuring continuous and efficient support throughout the journey.

The proposed work will ensure that ambulances are given priority at every intersection they approach, with signals automatically turning green before the ambulance reaches the junction. The planned vehicle speed of 100 km/h in Bypass Road within the city limit 60km/h. The objective is to make green corridors a standard feature of emergency response infrastructure in congested urban areas, thereby reducing delays, improving scalability, and enhancing response times for all emergency services. The proposed work will be automated using real-time vehicle density data captured through cameras. By analyzing live traffic conditions at intersections, the system will calculate optimal durations to reduce congestion.

Main contributions of the paper

1. Integration of a hybrid intelligent system consisting of Binary Particle Swarm Optimization (BPSO) and Multi-Level Priority Dynamic Scheduling (MLPDS), which identifies ambulances 200 meters ahead and controls traffic signals in real-time depending on real-time congestion and patient severity to provide uninterrupted, delay-free travel without human intervention.

2. Developed a dual verification system that integrates geotagging with YOLOv11 (You Only Look Once) cameras enabling the identification of ambulances under challenging conditions and adapts routes in response to obstacles or detours.

3. Real-time notifications give traffic stations and hospitals patient severity levels and Estimated Time of Arrival (ETA). This makes hospitals ready ahead of time and traffic stations clear the way efficiently, enhancing emergency response and decreasing delays.

1 Literature Review

Extraordinary rise in the number of vehicles in India over the last few decades has outpaced the development of road infrastructure, thereby causing continuous traffic congestion, particularly in metro cities such as Delhi, Mumbai, and Bangalore[14]. These cities experience not only the high volume of vehicles but also the complexity of mixed traffic[15]. All type of vehicle from cars, motorcycles, auto-rickshaws, buses, and trucks navigates through same two-line roads. This varied mix, on top of unplanned urbanization and narrow streets, leads to worse the congestion, frequent traffic jams and longer travel times[16]. Conventional systems often fail to suit the dynamic nature of traffic in urban areas. For emergency vehicles, the current system depends on traffic police to manually change the directions of traffic signals and nearby vehicles make way, which is not only slow but also leads to human error. When an emergency vehicle suddenly enters an intersection, the siren sound confuses other vehicles that causes inappropriate maneuvers and finally leads to collisions and traffic jams which increases response times[17]. Such dependency on manual control suggests the limitations in responding real-time changes, like roadblocks or construction work or accidents, disrupting traffic further.

In addition, current fixed-timed static traffic lights cannot handle the fluctuating traffic density at different times of the day, leading to inefficient traffic management in peak hour and emergency situations. This signal allocation can result in crucial delays either during the peak hours when the density of traffic is highly variable, or at off-peak times, when roads may be free, but cars still need to wait for the red light. As a remedy, some complex intersection such as five-arm or six-arm junctions, traffic is often routed through roundana to reduce stoppages[18]. Then constructed flyovers on the main roads of cities to divert main traffic from local roads thereby reducing pressure on intersections[19]. Flyovers do help in the separation of high-volume routes but do not thereby alleviate traffic congestion, especially during low-level intersections. Even in these techniques, however, the pressure of heavy traffic in highly congested areas prove problematic. These limitations of the traditional methods imply problems remains largely due to dependence on manual management and highlights the pressing need for automated and adaptive traffic management systems to help reduce India's growing traffic problems[20].

The need for smarter traffic management system that can adapt to real time scenarios by utilizing advanced technology like V2X communication[9], intelligent sensors[21], and automated signal adjustments[22]. The timely arrival of emergency vehicles can be an all-important factor for saving the patient in such cases of accidents and sudden medical emergencies. Thus, in such countries as India, where traffic congestion seems unpredictable and creates a blockade on roads often, it would be technically challenging to meet the required response times. Most critical situations are determined to have better survival rates with lower emergency response times[23]. It is hard to bring down the response times to the minimum required. Fixed-time signals do not adapt quickly to the emergency-changing needs of an emergency, and therefore delays can prevent emergency vehicles from arriving in a rescue zone or hospitals in a short period[24]. Fixed-timed signals and manual control systems are not able to adapt quickly to the dynamic needs of an emergency. This results in delayed movements as emergency vehicles get stuck up in traffic or faced obstructions[25]. It would considerably affect the ability to reach hospitals or rescue zones shortly. For addressing that, the term called as "green corridor"[26] was created. It gives priority to increase the speed at which an emergency vehicle can travel in traffic. Its purpose is to reduce the travel time of emergency vehicles[27]. Primarily it was created for organ transplants.

In the world, Berlin and Los Angeles, have implemented successful implementation of green corridors for emergency services through real-time traffic management systems[12], which reroute vehicles to create dynamic paths for emergency vehicles. While there is improving development in using RFID, V2X, and Geofence technologies[9] for managing these corridors, there are some challenges yet to be overcome to optimize the systems against more reliability and wider use. Analyzing current technologies, the RFID-based systems[28] at road junctions automatically identified ambulances and changed the traffic lights to green as the vehicle approached. RFID tags attached with the emergency vehicles communicate with the RFID readers installed at junction, the traffic management system is notified to change the flow of vehicles in real time. Though RFID systems work effectively in minimizing delays at road junctions, a single technology doesn't solve the problems in a congested urban city environment because many junctions are often involved, and possibilities for the detection of failure cannot be avoided[29]. For example, the inability of an RFID reader to detect an arriving vehicle, due to interference[30] by the signal or limitations in the infrastructure over the ground, may cause an entire breakdown in the system.

Because of this, computer vision-based techniques like object detection, are new and better ways to reduce this risk. The You Only Look Once (YOLO v8) a state-of-the-art object detection model, implemented in Singapore and South Korea[31] to detect the passing of an ambulance or fire truck proxy in real time for immediate, automated signal adjustments without human intervention, therefore reducing response times. This might require training YOLO model with custom datasets for actual cities. But various vehicles also differ in size, color, etc., across different regions[32]. Another method, V2X communication technology, has proven to be a game-changer in Germany, allowing real-time communication between emergency vehicles and traffic lights[33]. With V2X, automotive vehicles can send warnings to traffic infrastructure and other cars, creating intelligent green light corridors without human intervention. It has been most useful in urban situations where emergency response times are cut as traffic lights turn green and regular traffic makes way. However, in India, this technology faces challenges due to high vehicle density and the inability to deploy it widely into daily-use vehicles, making it infeasible for cities like Mumbai in the short term[34].

Geofencing is a technology that creates virtual perimeters around the GPS-radius specific areas. A cluster geofencing allows for the automated activation of green corridors when an emergency vehicle enters a predefined geofence[35]. The same method is used in Bangalore, where a geofenced system controls the green corridors for ambulances toward K.C. General Hospital, with the system controlling the traffic light in a 50-meter radius of the junction[36]. However, one weakness of such solutions now is that geofencing alone can sometimes create a confusion problem at the traffic station. Every time an ambulance enters a geofenced area, traffic operators can get confused in trying to identify the exact direction from which the vehicle is coming, hence delaying changes to the traffic. Proposed system improves geofencing by providing a greater understanding of the exact direction and distance of the ambulance from the junction. Acoustic sensors for detecting emergency vehicle sirens, offering a reliable solution for traffic management at junctions. These sensors have been effectively used in cities like Stockholm to enhance GPS-based systems for emergency vehicle detection[37]. With the addition of geotagged GPS data, this device-coupled proximity and acoustic sensor setup can respond better, seamlessly, and more accurately, reducing confusion and allowing

quicker decision-making at road junctions.

In India, geofencing and GPS integration dynamically adjust traffic signals, allowing ambulances to navigate congested roads more efficiently[7]. This system reduces response times by enabling precise routing and real-time adjustments to traffic conditions. However, for patient severity and hospital information, an additional server is required to trigger the traffic management system[38]. Continuous traffic signals are geofenced in cases where they are consciously triggered. The ambulance management app, configured with navigation software, transfers location data to a central server that transforms the data into green corridor actions. A hurry-call mode via API is called to Adaptive Traffic Control System (ATCS) traffic control software, which triggers traffic junctions by enabling or disabling the hurry-call feature. This system is essential for services like organ transplants, requiring a dedicated center control server. In Hyderabad, GIS technology is integrated with geofencing to enable the real-time manipulation of traffic signals. This allows ambulances to bypass congested areas and navigate quicker routes.

The proposed system integrates geotagging, camera-based YOLO detection, and GPS in a multi-layer verification process to give an optimal solution for Indian cities. Using GPS with geofencing to manage traffic signals dynamically and in real-time increases system responsiveness. The use of geotags along major routes will help keep track of ambulance locations, continuously changing signals as the ambulance moves through the city, thereby reducing delays. GIS provides complex spatial analysis of traffic flow, allowing for better routing decisions at congestion hotspots. The system overcomes the limitations of existing technologies by improving detection accuracy and making the system adaptable for large use case beyond organ transplant ambulances. This integration also ensures scalability support to all emergency vehicles in congested urban traffic.

2 Identified Research gap

1. Manual RFID-based systems are limited in detection, particularly when Heavy Motor Vehicles (HMVs) block emergency vehicles communication. Geotagging 200 meters prior to junctions improves detection accuracy and minimizes dependence on RFID technology. the rfid reader need to fix at every junction

2. Limited no of ambulances support due to RFID and Vehicle Mounting Unit (VMU) dependency can be addressed with geotagging and camera-based detection, support Green Corridor access for all emergency vehicles.

3. Manual hospital notification slows down emergency responses. Automated systems with patient severity information facilitate quicker, more reliable communication among ambulances, hospitals, and traffic controllers.

4. v2x sensors uses 8-meter range V2X sensors are not adequate for timely notifications. 200-meter detection geotags provide precise signal tuning and more fluid traffic.

5. Existing systems do not have dynamic traffic management on multi-junction routes. Adaptive signals and real-time path recalculation guarantee unimpeded passage through diversions and varying traffic densities.

3 Preliminary

3.1 YOLO v11 for vehicle detection

YOLO v11 is a state of art object detection model that optimizes real-time performance[5]. This model applies the backbone network along with CSP (Cross-Stage Partial) layers for feature extraction and Path Aggregation Network, (PANet) for feature aggregation, ensuring multi-scale detection accuracy. It makes use of anchor-free detection along with Complete Intersection Over Union (CIoU) loss to provide precise localization. The model can process at 30 FPS and deals with complex traffic conditions like occlusion or low visualization. The model is ideal for dynamic emergency traffic management due to its balanced architecture in terms of speed and accuracy.

3.2 GPS (Global Positioning System)

The GPS (Global Positioning System) plays a crucial role in the green corridor system by providing real-time location updates for ambulances. Its architecture, comprising satellites (space segment), ground control stations (control segment), and ambulance-mounted GPS receivers (user segment), ensures continuous tracking with a positional accuracy of up to 3 meters. Location data is updated every 2 seconds and integrated with GIS to calculate and dynamically adjust the shortest and most efficient route to the destination, accounting for traffic conditions and deviations. This seamless tracking enables real-time traffic signal management and ensures that emergency vehicles maintain uninterrupted passage through intersections, optimizing response times in critical situations.

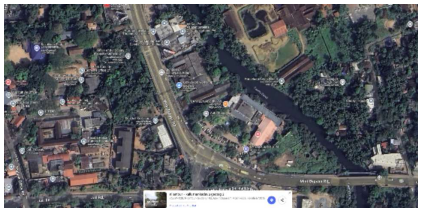


Figure 1. Geo statical representation of Kalluthankadavu junction Geotag pinpointed

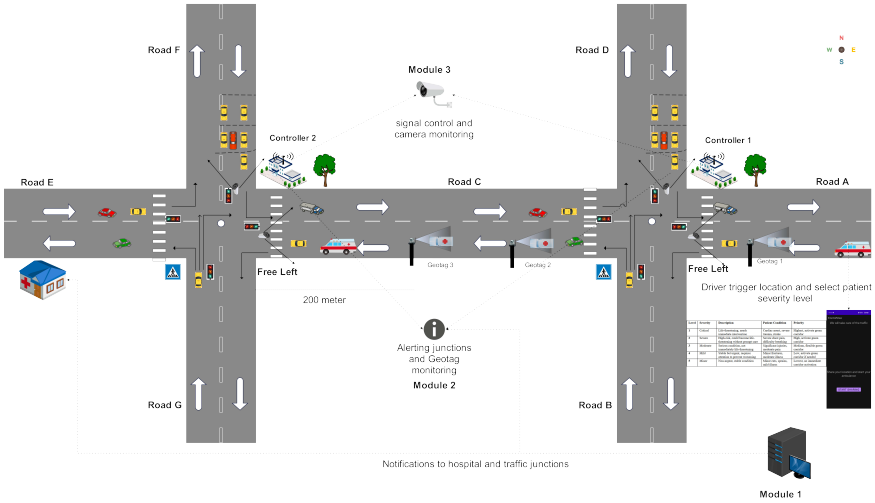


Figure 2. Proposed methodology interconnected junction layout

3.3 Geotagging

Geotagging defines critical zones, such as 200 meters before junctions, using latitude and longitude coordinates. It is GPS data that is used to trigger actions like green light activation or route recalculations.

Dual verification reduces false triggers and supports dynamic updates for route changes. With GIS integration, geotagging provides a spatial overview of ambulance movements and traffic adjustments. Fig 1. illustrates the geospatially pinpointed location of Kalluthankadavu Junction used as the reference point for the proposed methodology.

4 Proposed methodology

The methodology proposed aims to create an automated system of green corridors specifically designed for emergency vehicles, where the latest technologies such as GPS, GIS, geotagging, and YOLO-based object detection ensure smooth passage for ambulances. This system, therefore, aims to work on dynamic traffic signal control, real-time route correction, and minimizing the overall interference in the normal stream of traffic. Fig 2 illustrates the proposed methodology for the interconnected junction layout, while the corresponding block diagram is presented in Fig 3. Each of those modules are explained in the following sections.

The system as a whole uses technology such as GPS location tracking, GIS for geotagging, YOLO-based vehicle recognition through object detection, and real-time hospital and traffic controller notifications. All these modules work in tandem to ensure an end-to-end solution in optimizing response times of emergency vehicles operating in an urban environment.

Module 1: Real-Time Data Streaming

This module gathers real-time location data from the ambulance, capturing the severity information for the patient; this includes whether the condition is critical, urgent, or stable in order to prioritize emergency response. Using a mobile application, the driver will initiate location streaming, select the level of severity by the patient, and receive a list of the nearest hospitals by a radius of geolocation using cluster geofencing via an API. The selected hospital's details, along with the ambulance's real-time longitude and latitude, are sent to the server. This data is used to prioritize the patient and calculate the optimal route to the hospital based on current traffic conditions.

Module 2: Route Calculation and Notification System

This module determines the most direct and efficient path to the designated hospital while simultaneously ensuring that essential

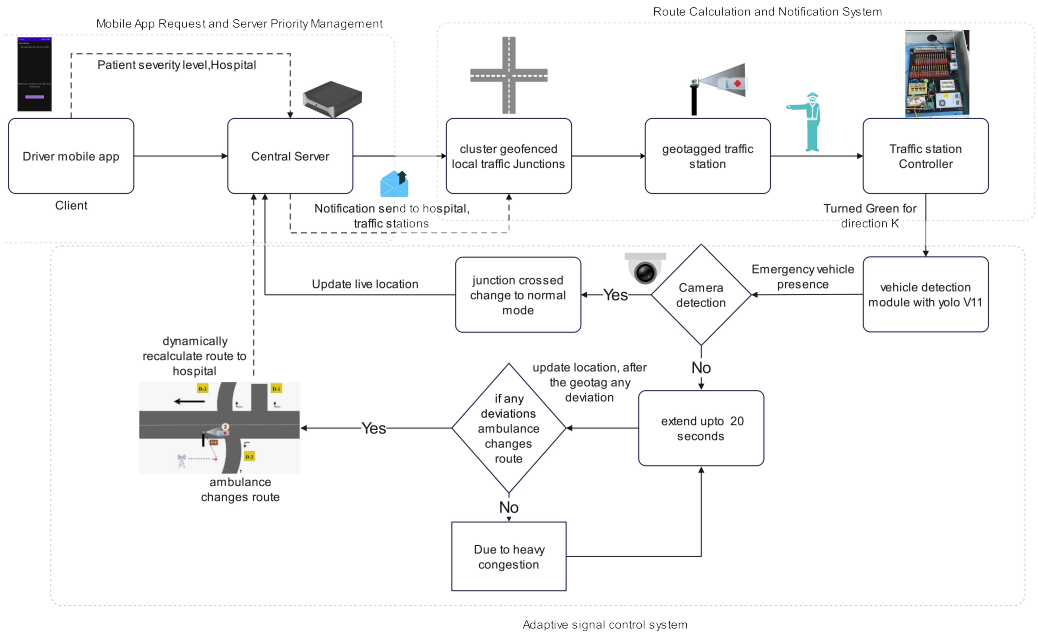


Figure 3. Block diagram

Table 1. Patient Severity Levels

Level	Severity	Description	Condition	Priority
1	Critical	Life-threatening, immediate care	Cardiac arrest, trauma	Highest
2	Severe	High-risk, needs prompt care	Chest pain, breathing issues	High
3	Moderate	Serious but not life-threatening	Significant injuries	Medium
4	Mild	Stable but urgent	Minor fractures	Low
5	Minor	Non-urgent, stable condition	Cuts, sprains	Lowest

stakeholders are notified in real-time. The application provides the ambulance operator with ongoing updates regarding the optimal route and transmits alerts to the selected hospital to facilitate preparations for the impending arrival of the patient. Concurrently, traffic control authorities are informed about the ambulance's trajectory, thereby allowing for preliminary measures to be taken in activating the green corridor. This ensures a seamless loop of communication from the ambulance, hospital, and traffic control toward efficient response in an emergency.

Module 3: Adaptive Signal Control System

It uses geotag and camera-based verification to dynamically control the traffic lights for emergency vehicles. When the ambulance enters a geotag zone (200 meters before the junction), the traffic lights automatically switch to green, thus clearing the road for it. The YOLOv11-powered cameras at the junction visually verify the presence of the ambulance therefore, it acts as a dual verification system with zero false positives. The server processes real-time location data every 2 seconds, updating signals and recalculating the route for deviations or roadblocks. If the ambulance is delayed due to traffic density, the green light duration is extended by 20 seconds, ensuring smooth and prioritized passage.

5 Operational pipeline

5.1 Module 1: Smart Emergency Response and Priority Routing System

The system will start, when the ambulance driver opens the Application and trigger the live location Fig 4. After activation, the driver will select the patient severity level based on the patient conditions table shown in Table 1. The app shows the nearest hospital in the 50-kilometer radius based on the severity level of the patient. After the driver chooses the hospital, the route map

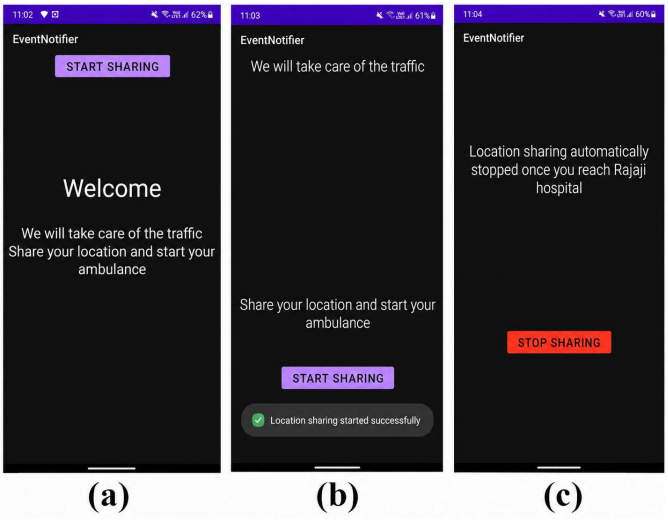


Figure 4. Snapshots of ambulance location streaming from the application

is calculated for the destination (Hospital) using the haversine distance[39] and Google Map Developers API.

This input data is critical to prioritizing the ambulance and ensuring the nearest hospital notified in that time. This app information sends to the server, which handles decision making, prioritization and route-signal optimization.

The central server checks the severity level of the patient and live-location streaming, to trace the location of the ambulance, and gives the shortest route from the current location to the nearest hospital. The route calculation integrated with the Google Map Developer API, it searches the nearby hospital within the radius, it automatically shows hospitals by shortest distance. Once the route is calculated shows in (1), the green corridor system becomes active along the calculated route. Hospitals (H1) are sent notifications in such a way that the medical team can prepare requirements to save the patient. The flow diagram of Module 1 is illustrated in Fig 5. In order to manage traffic concurrently, geotagged police personnel cabins along the route

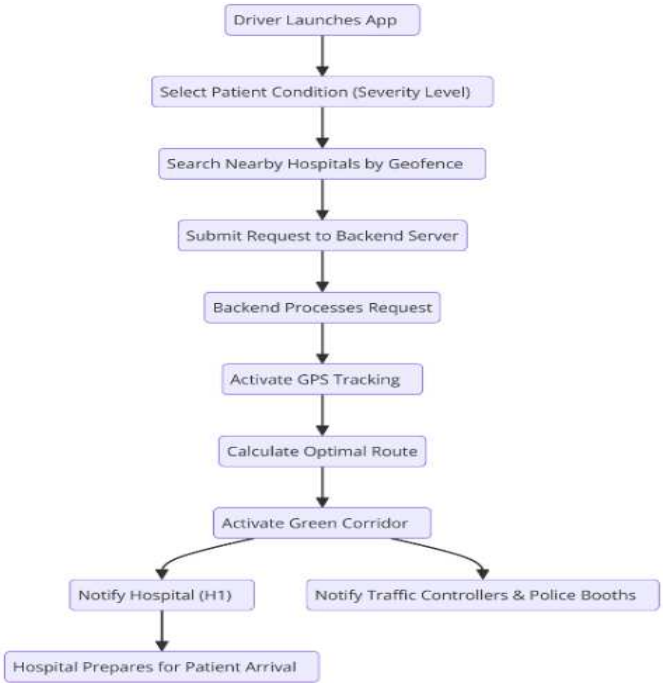


Figure 5. Flow diagram for module 1

and traffic junction controllers both get notifications at the same time. Every traffic authority is ensured to be notified of the ambulance's movement and if need to provide assistance to provide assist

$$d = 2R \cdot \arcsin\left(\sqrt{\sin^2\left(\frac{\Delta\theta}{2}\right) + \cos(\theta_1) \cdot \cos(\theta_2) \cdot \sin^2\left(\frac{\Delta\lambda}{2}\right)}\right) \quad (1)$$

Equation 1 shows the haversine formula. In this, the latitude and longitude of both points are first converted from degrees to radians.

The differences between the latitudes and longitudes are calculated as

$$\Delta\theta = \theta_2 - \theta_1 \quad \text{and} \quad \Delta\lambda = \lambda_2 - \lambda_1$$

These differences are used to compute the sine and cosine functions to account for the Earth's curvature. Specifically, the term $\Delta\theta$ measures the north-south distance, while $\cos(\phi_1) \cdot \cos(\phi_2)$ adjusts for the Earth's shape at varying latitudes. The final term, $\sin^2\left(\frac{\Delta\lambda}{2}\right)$, handles the east-west separation.

The function $a = \sin^2\left(\frac{\Delta\theta}{2}\right) + \cos(\theta_1) \cdot \cos(\theta_2) \cdot \sin^2\left(\frac{\Delta\lambda}{2}\right)$ computes the angular distance between two geographical points.

This angular distance is then related to the Earth's center. The physical distance d between the two points can be computed using the Haversine formula, where r is the Earth's radius, approximately 6,371 kilometers. Multiplying the angular measurement by $2r$ gives the actual physical distance between two points in kilometers. The destination hospital H_1 distance is calculated from the destination point of the ambulance.

5.1.1 Communication between Mobile app to traffic signal controllers

LoRaWAN, is a Long-Range Wide Area Network[40], acts as the basic communication protocol connecting mobile applications with traffic signal controllers, hence enabling the smooth transfer of essential information such as the location of ambulances, the levels of patients, and signal priorities. The LoraWAN protocol specifications to the green corridor are shown in Table 2.

Table 2. Benchmark Specifications for LoRaWAN Communication System.

Benchmark Specification	**Details**
Protocol Type	Long-Range Wide Area Network (LoRaWAN)
Operational Latency	10–50 milliseconds
Data Transmission Rate	0.3 kbit/s to 50 kbit/s per channel
Frequency Band	Sub-GHz: 868 MHz (Europe), 915 MHz (North America), or 433 MHz (Asia)
Coverage	Rural areas: 10–15 km; Urban areas: 2–5 km
Throughput Capacity	12,000 messages per hour, ensuring reliable updates across geotagged junctions
Simultaneous Alerts	Supports alerts for 200 geotagged junctions simultaneously
Power Consumption	˜0.1W (Idle), ˜2W during transmission; Energizer Ultimate Lithium AA batteries ensure 5+ years of operation
LoRaWAN Module	RAK811 LoRa Module (supports up to 22 dBm transmit power, 3.3V DC input)
Sensors	Semtech SX1276 transceiver for LoRa communication; optional integration with DHT22 sensors for ambient monitoring
Interference Resilience	Strong signal penetration through buildings, tunnels, and dense urban interference
Synchronization Time	Dynamic updates within 2 seconds for all geotagged controllers during route deviation
Transmission Reliability	99.8% reliability verified through field tests with 10,000 packets, of which only 20 experienced delays or retransmission
Response Improvement	Reduces ambulance travel time by 40–60% compared to manual signal handling systems
Battery Type	Lithium-ion battery (3000 mAh) for backup
Security	AES-128 encryption for secure data transmission

In the case of route deviation, the protocol dynamically updates all the geotagged controllers within 2 seconds for maintaining synchronization in the green corridor system. As a result, response delay is minimized by ensuring sub-second data transmission between the mobile app and traffic controllers and reducing ambulance travel time by up to 40–60% compared with the manual signal handling systems.

5.2 Module 2: Adaptive Junction Alert System with Real-Time Geotag Monitoring

After the central server request, the system depends on geotags (longitude and latitude coordinates) and ambulance live-location to continuously monitor the location and arrival of the ambulance after receiving a request from the central server that prioritizes the shortest path. To provide the traffic controller system enough time to get ready for the ambulance's approach, each traffic intersection is geotagged 200 meters in advance. The system will simultaneously alert the geotagged police booths and traffic signal controllers whenever an ambulance arrives at this geotagged region, alerting the police officers of the ambulance's direction.

At the same time, the system automatically picks up geotag points along an alternate route where diversions or roadblocks are causing changes in the route of the ambulance is shown in Fig 6. These geotags ensure to keep green signals going on along the new route so that the route remains uninterrupted with the ambulance. A two-step verification mechanism enables the system to adapt dynamically to real-time route alterations, thereby ensuring continuous and uninterrupted ambulance transit.

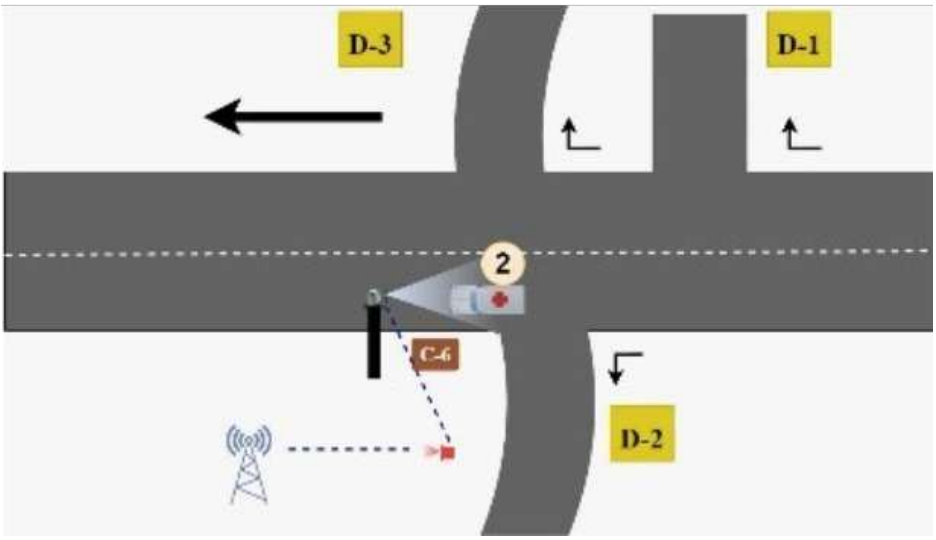


Figure 6. Deviations in road

To Calculate, Average speed of the emergency vehicle route, to arrive at the hospital in time, where conditions and road blocks are more likely to alter the designed route[41]. For accurate calculations, the ambulance route can be divided into multiple intervals, enabling real-time tracking of the vehicle's movement across different segments of its journey.

In equation 2, An interval (i) refers to that section of the ambulance route, which can be described with reference to: distance covered between two important points-for example, lights or crossroads, time taken to cover each of those parts-time gap, for example, every 5 or 10 mins. Road conditions during that journey-flowing traffic, road blocks, and diversion. This interval helps in more precise calculation and deviation of the route, taking into account the real-time conditions the ambulance encounters.

The average speed of the ambulance, considering the entire route, is calculated by sum the distances covered in each interval and dividing by the total time taken for those intervals.

$$S_{avg} = \frac{\sum_{i=1}^{n} D_i}{\sum_{i=1}^{n} t_i} \tag{2}$$

Here, D_i represents the distance covered during interval i, while t_i denotes the time taken to travel that distance during the same interval. The variable n indicates the total number of intervals considered along the route.

After calculating the average speed of the ambulance, estimating the Expected Time of Arrival (ETA) to Hospital H1 becomes important for effective real-time traffic control. The accuracy of ETA estimation in congested areas is influenced by factors such as road conditions and traffic vehicle density. To estimate the ambulance's ETA under real-time traffic conditions, Equation 3 uses the distance D to the hospital together with the average speed S of the ambulance:

$$\text{ETA} = \frac{D}{S} \tag{3}$$

In urban environments where traffic conditions can change rapidly, a congestion factor X is introduced to adjust the speed of the ambulance in response to traffic density. This congestion factor modifies the ambulance's base speed based on real-time conditions. The effective speed $S_{\text{effective}}$ is calculated as:

$$S_{\text{effective}} = S_{\text{normal}} \times (1 - X) \tag{4}$$

Here, S_{normal} represents the normal speed of the ambulance, and X is the congestion factor, ranging between from 0 (no congestion) to 1 (Maximum congestion). For example, if X is 0.3, it indicates moderate congestion, and the ambulance will travel at 70% of its base speed. If X is 0.7, it indicates high congestion, and the ambulance will travel at only 30% of its base speed. This adjustment ensures a more realistic estimate of travel time by factoring in traffic delays. Here, the adjusted speed, the ETAnew is calculated as in 5;

$$\text{ETA}_{\text{new}} = \frac{D}{S_{\text{effective}}} \tag{5}$$

Meanwhile, police stations along the adjusted route receive updated notifications, enabling officers to clear traffic or provide additional support in necessary situation. This continuous geotag-based tracking ensures that emergency vehicles always have priority based on severity level , regardless of route changes, reducing the dependency on human intervention and improving response times.

5.3 Module 3: Adaptive traffic control management

As the ambulance approaches the 200 meters before junction, the MTC2E optocoupler will handle region of interest (ROI) are drawn at 200 meters. The ROI drawn in junction respectively. Each zone drawn 50 meters. For each direction 3 zones are drawn for vehicle density calculation. In the region, ambulance presence controller will trigger the light to the corresponding direction. The proposed traffic junction controller shown in Fig **??**. The controller majorly optimizes the size with Webster's



1) 240V to 24V SMPS
2) 12V DC to 5V AC converter
3) Raspberry Pi 4 model B
4) MTC2E Optocoupler Interface card
5) Vega Board V 2.0
6) Output relays
7) 32 relays
8) Output to traffic lights
9) 250 W power connection
10) Main PCB switch
11) power connection soldering
12) connections to vehicle detection module

Figure 7. proposed traffic junction controller connection

equation 6, without affecting the normal cycle. traffic signal timing adjustments for emergency vehicles, for signal optimization Webster's formula for calculating the optimal cycle length for traffic signals, the Webster's formula is used for optimizing traffic signal timing to ensure smooth traffic flow, particularly in scenarios involving emergency vehicles like ambulances. The formula calculates the optimal cycle length for traffic signals, represented by the variable C, which ensures minimal delay and efficient traffic management. In the equation:

$$C = \frac{1.5L+5}{1-Y} \tag{6}$$

Where C denotes the optimal cycle length of seconds, total time required for one complete cycle of the traffic signal, which in fact includes the green, amber, as well as red phases of all directions at an intersection. L refers lost time per cycle, where lost time is time lost by start-up and clearance periods at the beginning and end of each signal phase. It might be related to the vehicle starting time from stand still or the time required before the next phase of the interchange. Y is sum of critical flow ratios for each of the signal phases. It can be calculated using actual traffic flow rate as the sum of division of capacities of the

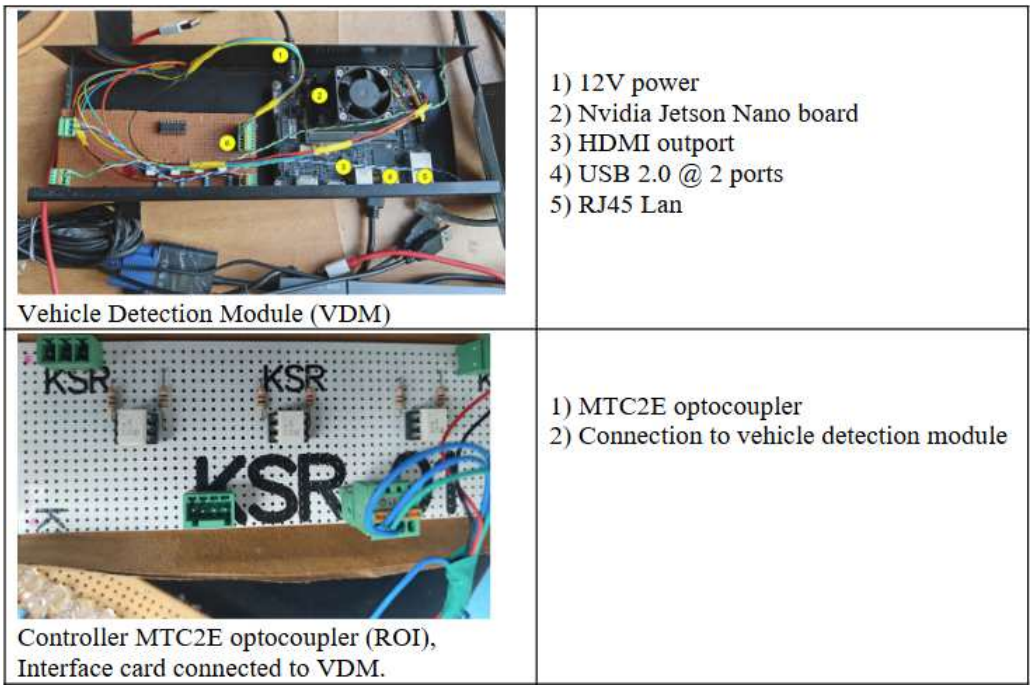


Figure 8. vehicle detection module

intersection for each phase, all directions respectively. The higher the sum of those flow ratios, the more traffic volume an intersection has to handle and the optimal length cycle of the signal is influenced.

At each direction in junction, cameras are mounted with YOLO v11 vehicle detection module shown in Fig 8, which processes live video streams at a resolution of 1080p by covert the frames to aspect ratio of 640×640 to improve detection accuracy. With a detection confidence threshold set at 0.8, it ensures reliable identification, even in dense traffic conditions. The moment an ambulance crosses the 200-meter geotag zone, the system starts traffic signal changes through the MCT2E optocoupler module , in-built with the system and allows for priority passage for the ambulance route without disrupting the regular flow of traffic (Fig 9). Real-time alerts are transmitted to traffic controllers and geotagged police booths via LTE/5G communication, thereby facilitating real-time coordination. This way, the system can process a frame up to 30 fps and ensure the timely update and robust detection within dynamic traffic scenarios. If the ambulance clears the junction within a time



Figure 9. Snapshots of the Ambulance passage in the junction

threshold of 25 seconds, the system instantly switches the traffic signals back to their normal rotation mode. However, if the ambulance does not clear the intersection within this specified time interval, the system uses GPS to determine its position and extends the green signal by an additional 20 seconds. This strategy ensures minimal delays, even in complex traffic scenarios, while guaranteeing that the path of emergency vehicles is never disrupted. To support this degree of responsiveness, the system uses a hybrid control mechanism that integrates binary particle swarm optimization (BPSO) and multilevel priority dynamic scheduling (MLPDS). BPSO successfully identifies optimal green light configurations, with a computational complexity of $O(P \times D \times I)$, where P is the number of particles, D is the number of traffic junctions, and I is the number of iterations. At the same time, MLPDS offers a lean scheduling layer with a complexity of $O(N \log N)$, which dynamically prioritizes emergency

routes based on vehicle type, real-time traffic congestion levels, and the level of the patient's condition. Despite the two-layered architecture, the computational overhead remains relatively low, making the system well-suited for real-time deployment, especially on fog or edge computing infrastructure. Once the ambulance clears the intersection and crosses the 200-meter threshold on the other side, the traffic signals revert to normal operation, thus allowing for easy integration with normal traffic flow.

The fog computing environment is simulated using a distributed edge architecture with GPS-based localization and a 5G mesh backbone for node synchronization. Data preprocessing, dynamic traffic signal control, and task scheduling are performed independently by each node using multithreading. The system considers low-latency, guaranteed communication links and bounded propagation delay and is hence suitable for high-frequency emergency response applications.

5.3.1 Failure handling

In case of system failure, the central server communicates with the main controller, developed with an IoT-capable Raspberry Pi Model 4B board, to diagnose and repair problems in real-time. If the main controller is not responding or if the communication link between the controller and the server breaks down, then a vega board acts as a full fail-safe backup. The Vega board, which is equipped with an independent power supply, ensures that critical traffic signal operations, including normal flow regulation and switching to emergency priority mode, are not affected.

In case of a controller failure, the Vega board reverts to static signal timings that are established to ensure that traffic keeps flowing and does not stop. The fallback system retains essential operations and prevents a jam until the primary system is restored.

- In the event of a controller failure, the Vega board automatically switches over to predefined static signal timings. For example, high-density lanes are set for 30 seconds green light and low-density lanes are set for 15 seconds green light. Thus, traffic flow is uninterrupted by a static cycle until dynamic control is regained.
- A secondary communication module such as LTE working at 700 MHz or LoRa at 868 MHz will provide connectivity to the central server in case of any network outage. This module supports real-time updates and maintains control in emergency prioritization with a range of up to 15 km (LoRa).
- If server connectivity is lost, the Vega board will use locally cached geotagging data that are updated every 2 seconds to prioritize emergency vehicles. For example, it will continue to activate green lights within a 200-meter radius of the ambulance approach for real-time response.
- The system synchronizes operational data, which encompasses signal timing and traffic density metrics, with adjacent controllers every 5 seconds. Consequently, the maximum delay of maintaining coordinated traffic flow through junctions is 10 seconds during a single-node failure.
- There is manual control by virtue of a dedicated mobile application and physical switches with redundancy at junctions. One example of such control can be that it can initiate 25 seconds of green-light time on high-priority lanes within less than 3 seconds.
- The Vega board features a 12 V/7 Ah battery that enables up to 4 hours of backup in case of power outage, which in turn allows continuous operation during emergency priority switching and basic traffic management.
- The system will run at night from 11:00 PM to 6:00 AM in low-power blinking mode or shorten green-light intervals to 10 seconds. This reduces the energy consumption by as much as 40% without hindering the sufficient traffic flow for emergency events.
- In critical corridors, the degraded mode ensures that 50% of signal cycles Favour emergency vehicles. For example, green lights are held up for 20 seconds beyond the default timings, thus reducing delay by about 35% for ambulances in case of system disruptions

5.3.2 Algorithm 1: Emergency Vehicle Priority Optimization Algorithm

Emergency vehicles algorithm starts with initializing and setting up essential detection and communication protocols. At initialization, the system configures detection buttons for each major road (Zone A for Roads 1–4 and an additional Zone B for Road 1) and sets geo-tag triggers to detect incoming emergency vehicles within a 500-meter range of key junctions. This distance provides the system with enough time to prepare the traffic signals along the path for an approaching ambulance or other emergency vehicles. As part of the setup, a serial connection is established with the traffic controller to ensure smooth communication, and notifications are sent to the destination hospital regarding the patient's severity and estimated time of arrival (ETA). During the initial phase, all traffic lights are set to amber, indicating that the system is ready to operate in emergency mode if needed.



Figure 10. Kalluthankadavu junction



Figure 11. Kalluthankadavu junction (longitude :11.252673, latitude :75.792984)

5.3.3 Dual verification mechanism

The dual verification system is an important part of making green corridor frameworks reliable and accurate, especially within dense urban landscapes. The identification here is through geotags in combination with camera-based surveillance, which actually confirms the existence and movement of emergency vehicles. This alerts the geotagged zones within a certain range, generally 200 meters from a junction. The GPS coordinates automatically start sending pre-alerts to all junctions within proximity, which can prepare the system for adjustment of signals based on the estimated time of arrival (ETA). The cameras installed at the junction will visually identify the presence of an ambulance and accurately communicate its location to the traffic controllers and police officers with its direction.

The system recalculates the ambulance's route dynamically if an obstruction or a deviation forces a change of route, updating geotagged locations for the changed route to keep the controller constantly activated and prioritized. A two-level mechanism, with camera validation added on top of geotagging, responds to current conditions by mitigating potential risks from incorrect GPS readings or adverse visual scenarios like blockages or inadequate lighting.

6 Case study – kalluthankadavu junction

6.1 Location Map

The interconnected junction network selected for the Kozhikode case study, shown in Fig 10 and Fig 11 serves as the implementation site for the proposed automated green corridor model in Kerala, India. The specific focus for this work is on the Kalluthankadavu junction, part of a interconnection of roads that covers the Thondayad and Malaparamba junctions before connecting to the Kozhikode Government Hospital over 7 kilometers. Here a frequently experiencing traffic congestion due to its role as a key transit point coupled with a large population. Kozhikode is a fast-growing city that has mixed traffic of buses, cars, and two-wheelers, which gives a lot of challenges while managing traffic. This kind of location is ideal to test and evaluate the capabilities of the green corridor system in adjusting signals dynamically in a real-world, high-density traffic environment to help manage emergency vehicle passage appropriately.



Figure 12. NITC CVLA vehicle dataset collection

6.2 Dataset preparation

6.2.1 Dataset

The NIT-C CVLA personal Vehicles Traffic Dataset shown in Fig 12 and Fig 13 consist of 40000 images captured from various urban traffic intersections, such as kalluthankadavu, Thondayad , malaparamba Junction, palayam, KSRTC junction in Kozhikode. The dataset is split into 28000 images for training, 8000 for validation, and 4000 for testing. Each image is annotated with class labels coordinates to facilitate the real-time adjustment of traffic signals. The dataset was collected during different time intervals to capture a variety of traffic situations, including early morning, foggy conditions, morning peak hours (8:00 AM – 10:00 AM), afternoon under heavy sunlight (1:00 PM – 3:00 PM), evening peak hours (4:00 PM – 6:00 PM), and night traffic without sunlight condition (8:00 PM – 10:00 PM). The dataset includes diverse vehicle types, with a particular focus on emergency vehicles such as ambulances and fire trucks.

The proposed model exhibits strong scalability in high-load environments, supported by powerful fog node infrastructure. In our experimental setup, each fog node was configured with an Intel Core i9-13900 processor, NVIDIA RTX A4000 GPU with 16 GB GDDR6 VRAM, and 64 GB DDR5 RAM, enabling high-speed image processing and optimization computations in real time. As the number of emergency tasks increased from 100 to 1000, and the number of active fog nodes scaled up to 50, the system maintained an average decision latency of under 2 seconds. To ensure high-quality training data, the dataset was pre-processed by smoothing GPS coordinates to reduce variability and enhance reliability. A YOLO-based object detection model was utilized for identifying vehicles, including scenarios with occlusions, such as partial coverage by other vehicles. The dataset also categorized traffic densities, providing a rich set of conditions to improve the system's adaptability across various traffic environments and enhance its capability to manage emergency scenarios effectively.

6.2.2 Data preprocessing

In the data preprocessing phase, real-time video streams are received from cameras with a resolution of 4K (3840 x 2160 pixels) working at a frame rate of 24 Frames Per Second (FPS). Regarding the analysis of traffic signals, the red signal takes 45 seconds for all directions, which consequently may allow capturing only one frame every minute for each direction. To improve computational efficiency, frames with moving vehicles are captured at 1-second intervals, thus capturing data at a more frequent and dynamic rate.

Noise reduction techniques, including Gaussian and bilateral filters, are applied to ensure clarity of the data and enhance the

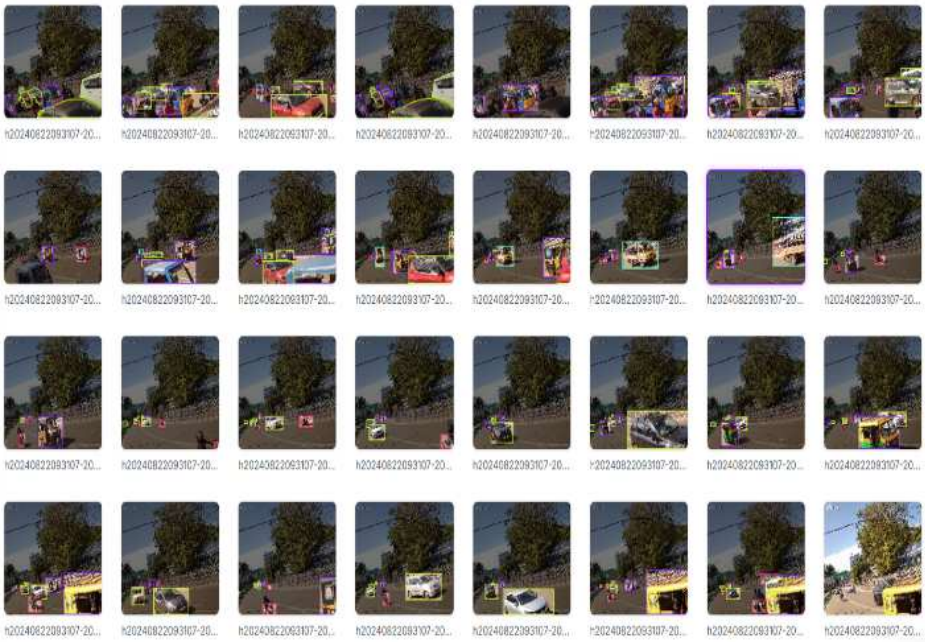


Figure 13. NITC CVLA annotated vehicle dataset

performance of the model. These filters help smooth out visual noise while preserving essential edges and details in the image. 1000 images are collected per vehicle class for testing purposes, providing a robust dataset for model validation and evaluation.

In preprocessing, initially the live feeds are taken from camera at 4k resolution (3840 x 2160 pixels) running at 24 FPS. In the junction the red signal for each direction 45 seconds then in a minute only one frame per minute possible. For moving vehicles Each frame is extracted at 1-second intervals to balance computational efficiency. Frames are resized to 640 x 640 aspect ratio, and the frames feed into vehicle detection module for the YOLO v11 trained model. Per class 1000 images taken for testing. Gaussian and bilateral filters used for noise reduction.

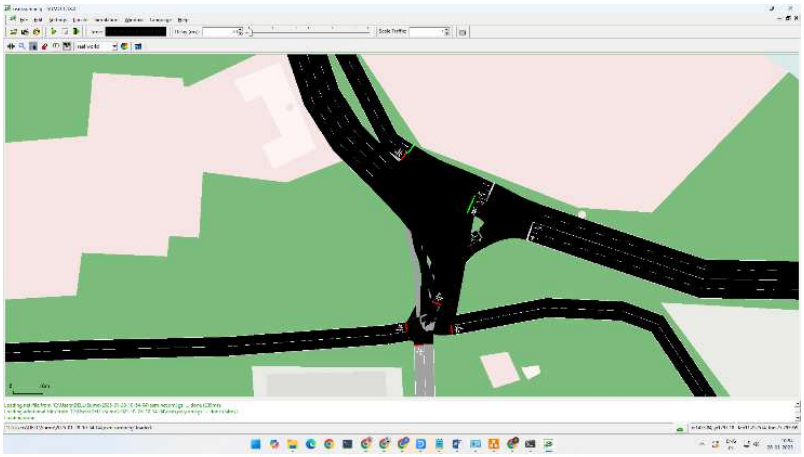


Figure 14. SUMO simulation in real time environment as kalluthankadavu junction layout

6.2.3 Data validation and annotating

Offline annotation tool Label Studio application was used to annotate the raw images(Fig 13), which is an open-source data labelling tool used for annotating data on machine learning and AI projects. The tool supports annotation of raw images with bounding boxes and is compatible with the format of the YOLO dataset. The annotated dataset is a combination of 12 class labels. Ambulances were annotated under different environmental conditions such as day, night, foggy, and rainy scenarios in order to capture diverse real-world situations. For the purpose of evaluating the model's performance on validation, images

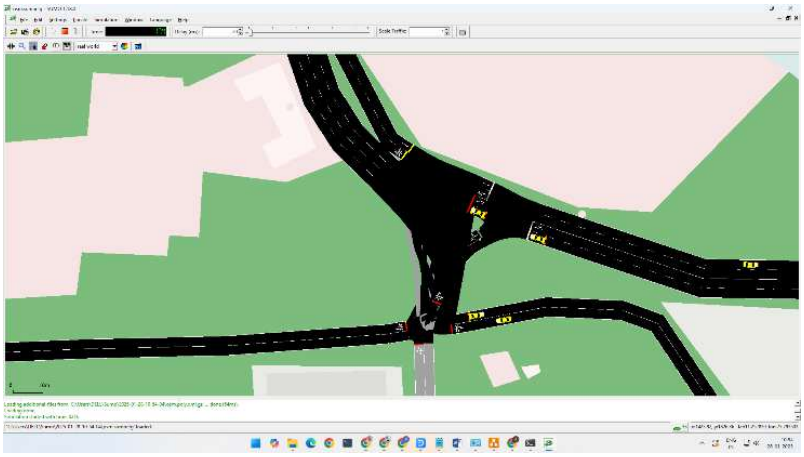


Figure 15. Real-time green corridor implementation

were captured especially from the most congested regions to simulate complex traffic scenarios. The dataset consisted of ten vehicle class labels, car, bike, auto, ambulance, police vehicle, bicycle, bus, tricycle, fire engine, and truck. Augmentation techniques such as flipping, brightness adjustment was done to increase dataset diversity and improve the generalization of the model during training. All the annotations were exported in YOLO format to train on the YOLO v11 object detection model. Train-test-validation split is performed by Python script where it followed 70% to 20% and 10%.

The proposed system was implemented and tested using the SUMO (Simulation of Urban Mobility) framework shown in Fig 14 and Fig 15 to simulate real-world traffic scenarios. Vehicle density was calculated in real time using camera-based detection integrated with the YOLOv11 model, ensuring accurate identification of emergency vehicles during high congestion. Geotagging was used to predefine zones 200 meters before intersections, dynamically triggering signal adjustments to prioritize ambulances. GPS data provided live location updates every 2 seconds, enabling precise route monitoring and efficient recalculations in case of diversions or roadblocks. The simulation results highlighted a 45% reduction in response time and seamless coordination between intersections, demonstrating the robustness of the system under varying traffic conditions.

In addition, the system was also made to adjust to different levels of traffic congestion through the implementation of a dynamic priority assignment system. This system used real-time traffic density information and historical congestion trends to dynamically adjust signal timing to provide optimal flow for emergency vehicles. Predictive analytics further improved the decision-making process by detecting potential traffic bottlenecks and modifying traffic signals accordingly. Furthermore, the use of GPS and geotagging by the system enabled continuous monitoring of emergency vehicles, allowing for timely adjustment of signals even in the event of unplanned detours. The results of the evaluation proved to confirm substantial improvement in emergency vehicle mobility, pointing to the system's potential as an effective traffic management optimization solution for urban settings. The sumo result shows a improves in the response time of ambulances after the implementation of the green corridor system. Before the implementation of the system, ambulances were forced to endure severe traffic congestion, causing a mean delay of 10 minutes per ambulance, which totaled 700 minutes for the 70 ambulances. After the implementation of the system, where emergency vehicles were prioritized at intersections, the mean delay per ambulance dropped to 5.5 minutes. This resulted in a total delay of 315 minutes, a 45% decrease in response time (Table 3). Enhanced coordination between intersections enabled the ambulances to travel more smoothly, resulting in a better efficiency in emergency response.

7 Performance Evaluation and Analysis

To evaluate the performance and effectiveness of the proposed automated green corridor system, a detailed analysis of real-world implementations in Indian cities is conducted. The focus is on measuring response time reduction, the impact on traffic flow, and the system's overall reliability in enhancing emergency services. Kalluthankadavu Junction was once a bottleneck point where traffic would congest, with the ambulance having to wait in long lines for several minutes. It depends on traffic police clearing the way, and clear vision was not possible at all times in this approach, making emergency response come through slowly. The evaluation metrics shown in Table 4.

The system used the facilities of CCTV cameras and geotagging and a mobile application that permitted the change of traffic lights automatically. Upon detecting an ambulance within 200 meters, the system turned the lights green to create a clear pathway. The travel time was reduced by 50-60% on peak hours and helped hospitals coordinate better with incoming emergency cases. The YOLO versions compared with the dataset shown in Table 5.

Results and Discussion

7.1 Impact of Technologies on Response Times

The comparative analysis among cities that used various kinds of technologies for implementing emergency corridors shows that geotagging and camera-based detection is better compared to the manual system and the RFID-based green corridors in reducing response times.

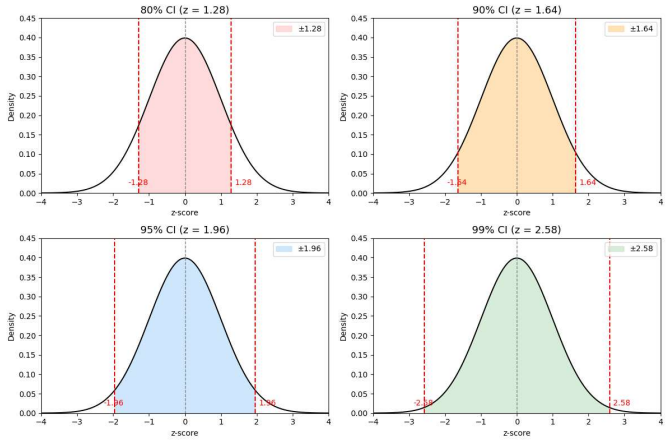


Figure 16. Impact of Technologies on ambulance response time reduction

The Table 6 shows the reduction in response times (in minutes) across different technologies according to fig 18. showing the 80%, 90 95%, and 99% confidence levels with corresponding z-values (1.28, 1.64, 1.96, and 2.58).

The response time of ambulances has significantly improved with the integrated technologies in traffic management as shown Fig 16. Initially, manual coordination could only bring a modest improvement of 12.5% as it was largely dependent on human intervention. The introduction of RFID-based systems improved efficiency by automatically activating traffic signals through RFID tags, thus reducing response time by 23.5%. Further improvements included geotagging with traffic cameras, where location of vehicles was tracked in real time and the flow adjusted to reduce by 40%. AI-based traffic prediction and machine learning algorithms like Random Forest and Gradient Boosting models that analyse traffic patterns and dynamically adjust signals to create green corridors, reducing by 50%. Integrated Emergency Networks came up with IoT-based frameworks that integrated ambulances, traffic lights, and hospitals to improve the response time up to 60%. Lastly, the methodology developed here combines AI with geotagging, vehicle density monitoring, and dynamic prioritization to smoothly manage traffic. The results end up at a 65% reduction. Such an approach to emergency traffic system management through the integration of sophisticated technologies is needed. Fig 17 shows the heatmap representation of key performance metrics of

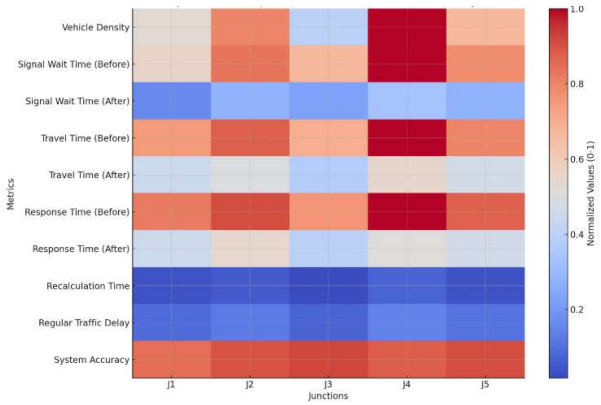


Figure 17. Impact of automated green corridor system

five junctions (J1 to J5) before and after the implementation of the automated green corridor system. In the above heatmap, which ranges from 0 to 1 for normalizing purposes, it can be clearly seen that most of the metrics have improved dramatically. The density of vehicles in the first row indicates the ability of the system to shift the density away from the congested regions.

Signal wait times and ambulance travel times show significant decreases, as shown by lighter colors in the ”After” rows, which indicate faster clearance and more efficient routes for emergency vehicles. The response time activation to hospital arrival is improved and highlight the accuracy of the system. The adaptability of the system is also reflected in the recalculation times, showing rapid route changes during deviations. Although the standard traffic delay row signifies negligible interruptions to nonemergency traffic, these delays are calibrated to sustain the overall flow of traffic. Therefore, the heatmap confirms that the system has high accuracy in detecting emergency vehicles and triggering green corridors, and its performance is optimal with the lowest false activation rate. Fig 18 illustrates the impact of training the dataset on ambulance response times. The geotagging and camera-based detection system shows the highest reduction in response times, compared to manual coordination and RFID-based systems.

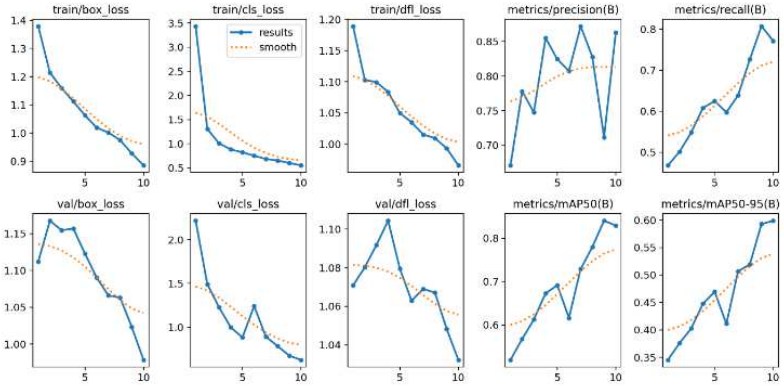


Figure 18. Training results

After the implementation of the proposed green corridor system, the evaluation metrics shown in Table 7 illustrate the traffic conditions before and after the deployment of the proposed technologies.

8 Conclusion and future work

The proposed automated green corridor system, as proposed, would represent a considerable gain in time that an emergency vehicle takes to reach the scene by virtue of incorporating YOLOv11, GPS, GIS, and real-time camera inspection. The preliminary results show that the travel time on the route has decreased by about 55% and the delay caused at a junction is reduced by 52%. Since the system is entirely automated in prioritization, it is free from manual errors, thus making it scalable and adaptable to distinct urban traffic conditions. However, problems qualified to be critical optimization areas like high vehicle density, unpredictability of traffic behavior and transmission delays remain obstinate.

In addressing these challenges, the future work will focus on that of real-time data accuracy-enhancing technologies, more advanced machine learning models for traffic forecasting, environmental parameters, such as weather effects. Prioritizing the extension of the multi-vehicle emergencies system to rural and semi-urban traffic environments will be implemented. These advances aim at the building of a robust adaptive framework ensuring seamless emergency response and enhanced public safety across the diverse regions.

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Author contributions statement

Jerline Sheebha anni and Prabu Mohadnas: Led the conceptualization and architectural design of a Green Corridor-Based Control and research in collaboration with KELTRON. Involved in data collection across multiple locations, conducted extensive experimental analysis, evaluated model performance, and enhanced the prediction accuracy through continuous model optimization Edited the paper and coordinated the final submission process.

Chin-Shi¬uh Shieh Mong-Fong Horng: Contributed to background research and the selection of appropriate machine learning techniques for the study.

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Algorithm 1: Green Corridor Algorithm for Emergency Vehicles

```
Step 1: Start the system;
Step 2: Configure vehicle detection buttons for Roads 1–4 in Zone A;
Step 3: Configure Zone B detection for Road 1;
Step 4: Initialize geo-tag triggers at 500 m before the junction;
Step 5: Establish serial communication with the traffic controller;
Step 6: Notify destination hospital (H1) with patient severity and estimated arrival time;
Step 7: Set all traffic lights to amber during initialization;
Step 8: Continuously monitor the traffic system;
while system is active do
    Step 9: Detect emergency vehicle using geo-tag trigger;
    if emergency vehicle detected within 500 m then
        Step 10: Notify nearby geo-tagged police booths for route clearance;
        Step 11: Set all traffic signals to red;
        Step 12: Identify the approaching road of the ambulance;
        if ambulance approaching from Road 1 then
            Step 13: Turn Road 1 signal green for 25 s;
        else
            if ambulance approaching from Road 2 then
                Step 14: Turn Road 2 signal green for 25 s;
            else
                if ambulance approaching from Road 3 then
                    Step 15: Turn Road 3 signal green for 25 s;
                else
                    Step 16: Turn Road 4 signal green for 25 s;
        Step 17: Check whether the ambulance has crossed the junction;
        if ambulance has not crossed after 25 s then
            Step 18: Extend green signal duration by 20 s;
        Step 19: Monitor GPS until ambulance crosses 200 m beyond the junction;
        Step 20: Restore normal traffic signal operation;
    else
        if time between 8:00 AM and 7:00 PM then
            foreach Road 1 → Road 2 → Road 3 → Road 4 do
                if vehicle detected in Zone A then
                    Step 21: Turn green signal ON for 10 s;
                else
                    if vehicle detected in Zone B (Road 1 only) then
                        Step 22: Extend green signal duration to 20 s;
                    else
                        Step 23: Turn green signal ON for 7 s;
                Step 24: Turn amber signal ON for 3 s;
        else if time between 7:00 PM and 11:55 PM then
            Step 25: Enable flashing amber signals for all roads;
Step 26: End the system;
```

Table 3. Comparison between static and dynamic traffic scenarios.

Direction	Static (Current Scenario)	Dynamic (Proposed Scenario)
Direction 1 Straight + Direction 1 Right	45 seconds	13 seconds
Direction 1 Straight + Direction 2 Straight	45 seconds	25 seconds
All Red	3 seconds	3 seconds
Direction 3 Right	45 seconds	6 seconds
All Red	5 seconds	5 seconds
Total Cycle Time	138 seconds	52 seconds

Table 4. Performance comparison before and after system implementation.

Metric	Before Implementation (Manual Control)	After Implementation (Proposed System)	Quantified Results
Route Travel Time (Total)	40 minutes	18 minutes	Reduced by 22 minutes, ensuring faster emergency response time
Junction Crossing Time	25 minutes	12 minutes	Saved 13 minutes, optimizing signal priority for emergency vehicles
Average Ambulance Response Time	40 minutes	18 minutes	Decreased by 22 minutes, improving patient survival outcomes
Travel Time Reduction (Peak Hours)	40 minutes reduced to 37 minutes	18 minutes	Significant improvement from 3 minutes saved manually to 22 minutes saved automatically
Manual Signal Handling Efficiency	Limited to 8% efficiency (52 sec to pass)	50–60% efficiency (24 sec to pass)	Automation eliminated delays, saving 15 minutes in signal adjustments per junction
Accuracy of Ambulance Detection	Limited (60–70% manually observed)	95%+ with YOLOv11 detection	Improved detection accuracy by 25–35%, especially in low-light and occluded conditions
Congestion Handling	Managed manually with slow adjustments	Automated and dynamic based on density	Real-time adjustments reduced congestion-related delays by 10–15 minutes per route
Scalability for Multiple Ambulances	Limited handling of 1–2 ambulances	Fully scalable for 5+ ambulances	Enabled simultaneous routing for up to 5 ambulances without conflicts
Notifications to Police and Hospitals	Manual calls required (1 minute needed)	Automated alerts with ETA and severity	Reduced communication delay by 5 minutes per emergency route
Integration of Technologies (GPS, GIS)	Only map and app (processing time over 25 seconds)	Fully integrated for dynamic adjustments	Real-time route recalculations saved 10 minutes in rerouting situations

Table 5. Comparison of YOLO models and the proposed system.

Metric	YOLOv4	YOLOv9	YOLOv11	Proposed System (YOLOv11)
Detection Accuracy (%)	87.5	93.2	96.7	97.5
Processing Speed (FPS)	45	60	72	70 (optimized for real-time signals)
Model Size (MB)	244	125	110	110
False Positives (%)	4.5	2.7	1.8	1.2
False Negatives (%)	6.8	3.2	2.1	1.5
Night Detection (%)	65	80	90	92
Foggy Weather Detection (%)	45	70	82	88
Adaptation to Indian Roads	Limited	Moderate	High	High with customized dataset additional training
Integration Capability	Moderate	High	Very High	Fully integrated with geotagging

Table 6. Average response time reduction achieved by different technologies.

Technology	Methodology	Average Response Time Reduction (%)
Manual Coordination	Basic human-led traffic control without automation [38].	12.5%
RFID-Based Systems	Use of RFID tags on ambulances to trigger green signals at nearby junctions.	23.5%
Geotagging + Cameras	Integration of GPS geotagging and traffic cameras to dynamically monitor and adjust traffic flow.	40%
AI-Based Traffic Prediction	Machine learning models such as Random Forest and Gradient Boosting for traffic prediction and signal timing optimization.	50%
Integrated Emergency Networks	IoT-based frameworks linking ambulances, traffic signals, and hospitals for real-time communication and route optimization.	60%
Proposed Methodology	Hybrid system combining AI, geotagging, vehicle density monitoring, and real-time signal prioritization for seamless ambulance movement.	65%

Table 7. Performance metrics and results of the automated green corridor system.

Metric	Methodology	Results
Ambulance Travel Time	GPS & GIS-based real-time routing	Reduced from 40 min to 20 min (peak) and from 25 min to 12 min (non-peak), achieving an average improvement of 18–20 min.
Detection Accuracy	YOLOv11 with OpenCV	Achieved 97% accuracy. Out of 1,000 frames, 970 ambulances were correctly detected, even in foggy and low-light conditions.
Signal Adjustment Time	Real-time geotag-triggered control	Improved from 10 s to 5.8 s, reducing intersection clearing delay by 4.2 s per event.
Congestion Reduction	Webster's formula-based signal optimization	Vehicle queue lengths reduced by approximately 30 cars per signal during peak hours. Average waiting time decreased from 2.5 min to 1.75 min.
False Trigger Reduction	Dual verification (GPS + camera)	False triggers reduced to 3%. Approximately 12 fewer false activations were observed weekly compared to manual systems.
Multi-Ambulance Handling	Dynamic geotag-based routing	Managed up to 5 ambulances simultaneously, each experiencing less than 5 min additional delay.
Route Flexibility	GIS-based dynamic recalculation	Adapted to 3 route deviations during peak trials. Dynamic corridor adjustment saved approximately 8 min per deviation.
Hospital Coordination	Real-time ETA notifications	Notification time reduced from 10 min to 6 min, enabling hospitals to prepare 4 min earlier for critical cases.
Energy Efficiency	Adaptive signal timing	Achieved 18% energy savings. Approximately 10 kWh was saved daily at Kalluthankadavu Junction, equivalent to powering 30 LED streetlights (100W) for 3 hours.