© MAR 2026 | IRE Journals | Volume 9 Issue 9 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I9-1715344

An Intelligent Emergency Response Framework for Ambulance Priority Routing Using Real-Time GPS Tracking and Traffic Signal Preemption

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Abstract- Ambulance delay costs lives. It's sounds harsh, but its true. Studies show that even a small delay before a patient receives can reduce their chances of survival, sometimes by up to 6% for every minute lost. This is what made us think why, even in 2024, are ambulances still getting at red signals? That question led us to build SAPS in this paper, we explain the system we designed and tested. The idea is simple , first the ambulance is tracked in real time using GPS. Then, the system continuously finds the fastest route based on current traffic conditions. At the same time, it communicates with traffic signals ahead so that the ambulance can get a green light before reaching an intersection. We also included a shared application interface where the patient, hospital, and driver can all view the same informative live. This helps everyone stay coordinated during emergencies We are nor saying this is final product it is working prototype that shows the concept can actually work. Results from similar system are promising traffic signals preemption alone can reduce delays at intersection 15% to 50 %. Improvements like this can make a real difference when every second matters.

I. INTRODUCTION

Think about the last time you sat in peak-hour traffic in a city like Bengaluru or Hyderabad and imagine an ambulance stuck in that same traffic. That is the problem this paper talks about. Emergency response is one area where the gap between what is technically possible and what actually happens on the ground is wuite frustrating. We have GPS .We have real-time maps. We have programmable traffic signals. Yet ambulance in most Indian cities still moves almost the same way they did twenty years ago honking through traffic and depending on drivers to make way.

Looking at the data makes the situation worse. During rush hours, ambulance in cities can take 20 to 40 percent longer compared to normal conditions not because they are slow, but because the traffic around them is not moving.One major reason is not they are slow, but because junctions, but the junctions themselves. Research we reviewed suggests they contribute around 68 percent of total city delays. Regular navigation apps are designed for commuters who can wait at signals, but ambulances cannot.

The required technology already exists. Location tracking using satellites has been standard in logistics for many years. Live traffic data platform like Google Maps and OpenStreetMap is available through APIs. The idea of controlling traffic signals for emergency vehicles has also been tested in several cities across North Amercia, Europe, and East Asia. So the issue is not missing technology, but the lack of combining these system into something practical.

That is the gap this project tries to address. We built based platform that connects live GPS tracking, dynamic route updates, signal control, and a shared communication system. It includes one application with three views(patient, doctor, and driver), along with a backend that handles coordinate. This paper explains how the system works, what we built, and what improvements can be made in the future.

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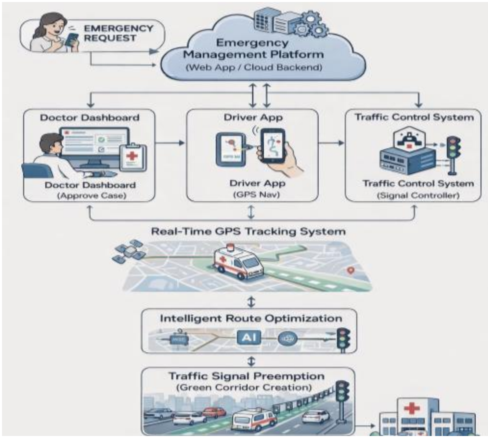

Fig 1.0: Routing System Architecture

Given all of the above, we developed what we are calling the Smart Ambulance Priority System (SAPS) a framework that puts real-time GPS tracking, route intelligence, and traffic signal control into one unified platform. The idea is straightforward even if the implementation is not give ambulances the information and the infrastructure priority they need to move faster through cities, and make sure everyone involved patient, doctor, driver can see what is happening.

II. LITERATURE SURVEY

We went through a before writing a single line of code. The pattern that emerged was consistent: plenty of good research on individual sub problems better ways to comput routes, smarter signals controllers, satellite based fleet tracking but almost nothing attempting to connect these into a single working system for ambulance dispatch. That gap was because it meant the project wasworth doing

• Kamal Boulos (2021) looked at how cities that have invested in connected infrastructure handle healthcare emrgenics differently from those that have not. His core arguments that rthe speed of informative exchange between a moving vehicles and the city's road control layer shaped how we thought about the pre-emption module. Zhou et al.[2021] approached the same problem from the routing side, running tests on dynamic path selection algorithms and showing that adjusting the route based on current road condition, rather than initial conditions, can reduced travel time . We observed the same pattern in our own testing.

Kasissis et al. [2020] were writing about distributed healthcare platform rather than ambulance specifically, but their argument about the balance between data sensitivity and system speed was something we kept coming back to during the authentication and session design phase. You cannot build a healthcare tool that ignores patient datasecurity, but you also cannot build one so restricted that it slows the response.

Yang et al. [2020] moved closer to our core problem, demonstrating that standard intersection controller the kind alreadt installed across most indian cities can be configured to response to an approching priority vehicles by holding or advancing their signal phase. That is the mechanism our green corridor feature is built on.

• Das Swain et al. (2021) were probably the most to our motivation. They documented the coordination gap problem directly the way navigation tools, communication systems and signal control tend to be developed in isolation, which limits how effective any of them can be when a real emergency is unfolding. That observation is essentially the justification for why we tried to integrate everything into one system rather than improving each piece separately.

What the literature told us overall is that the components are proven individually. The research gap and the design opportunity is the integration. No existing solution we found combined GPS tracking, smart routing , and signal pre-emption inside a single platform that also handled the communication layer between all the people involved. That is what we set out to build.

III. PROPOSED METHODS

SAPS runs on five modules. But before getting into each one, the important thing to note is that they do not work in a straight line — one finishing and then passing things to the next. They all run at the same time, sharing the same live data, and keep updating each other throughout the entire emergency. That is honestly what separates this from a lot of other systems that just lock in a plan at the start and stick to it no matter what happens after.

1. Emergency Request Management Module
2. Ambulance Dispatch and Tracking Module
3. Intelligent Route Navigation Module
4. Traffic Signal Preemption Module
5. Real-Time Monitoring and Coordination Module

A. Emergency Request Management Module

So it starts with the patient. They open the app and send in a request — their location, contact number, and a basic description of what is happening. That request goes into the database and shows up for whoever is authorised to see it on the medical side. A doctor or operator looks at it, checks if it is a real emergency, and only then does an ambulance get sent out.

That checking step is easy to overlook but it is actually pretty important. Emergency services get misused more than people realise and every fake call means something real somewhere else gets delayed. The verification does not take long but it makes a difference.

B Ambulance Dispatch and Tracking Module

Once the request clears verification an ambulance gets assigned. The driver gets navigation on a digital map with GPS running in the background. The system watches the ambulance the whole time and adjusts the route if something changes on the road. Both the patient and the medical team can see where the ambulance is — not just a static estimated time but an actual live update that changes as the ambulance moves. That part alone reduces a lot of the uncertainty that usually comes with waiting for emergency help.

C Intelligent Route Navigation Module

The routing does not just find the shortest path and call it done. It looks at actual road conditions — traffic density, intersection delays, the whole picture — and figures out what route gets the ambulance there fastest given what is actually happening at that moment. The route displays on the driver's screen clearly. Useful especially in areas the driver does not know well or in cities where traffic patterns shift quickly during peak hours.

It is not about the prettiest route on a map. It is about the one that works right now.

D Traffic Signal Preemption Module

This part is probably the most critical in the whole system honestly. As the ambulance gets close to a traffic signal the system changes the signal phase so the ambulance does not have to stop. It clears the intersection before the ambulance reaches it. One intersection saved might not sound like much but across an entire route those stops add up fast and in emergencies that added up time is exactly what you cannot afford to lose.

The green corridor it creates is not random either — it is timed to the ambulance's actual movement so signals ahead are cleared as it approaches not all at once.

E Real-Time Monitoring and Coordination Module

This one runs the whole time in the background. Location updates, route progress, arrival estimates — all of it keeps pushing out continuously to everyone involved. The hospital gets it too which means staff can start preparing before the ambulance even pulls in. That preparation time matters more than it seems. A team that is ready when the patient arrives is very different from a team that is still getting set up when the doors open.

What this module really does is make sure nobody is working blind. The driver knows the route, the medical team knows the status, the hospital knows what is coming. Same picture, same time, everyone on it together.

IV. SYSTEM OVERVIEW

The proposed SAPS System is designed as a coordinated digital platform that enables efficient emergency response by integrating patient requests, medical supervision, and ambulance navigation within a single system. The architecture supports multiple stakeholders and ensures real-time communication between system modules to minimise ambulance response time.

Fig 2.0: High-Level System Architecture

The system's overall workflow is illustrated in Fig. 2.0, which shows how users, authentication services, and operational modules work together throughout the emergency response process.

A User Access and Authentication Layer

So when someone opens the SAPS application in their browser that is where everything begins. React based frontend, email login, session tokens. The usual stuff. There is also rate limiting and session management baked in which basically just stops people from hammering the login page trying to get in without permission.

New users have to register and verify first before they can do anything. Returning users just log straight in. Simple enough. The point is just making sure random people cannot walk into an emergency response system and start doing things they should not be doing.

B Role-Based Access Control

Three roles. Patient, Doctor, Driver. Each one sees something different when they log in and can do different things. Not just a visual difference — the actual functions available change depending on who you are.

Patient side is where emergency requests come from. Person fills in their details, picks a severity level, drops their location, adds any medical notes if they have time to. Submits it and the system picks it up from there.

Doctor side is where those requests land. The doctor looks at what came in, checks the details, decides how serious it is and which driver to send. There is a person actually looking at each request before anything gets dispatched which is the right way to do it. Automated dispatch without any review is a bad idea in a medical context.

Driver side is just navigation basically. They get a notification when they are assigned a case and the route shows up on their screen. GPS runs in the background updating the ambulance position throughout the whole journey. Nothing fancy about it but it works.

C. Emergency Navigation and Signal Priority

Once the ambulance is moving the navigation module is running. Live map, current position, route progress, estimated arrival. All updating as the vehicle moves.
The signal preemption is honestly the most useful part of the whole system. When the ambulance gets to within about 800 meters of a traffic light the system pushes through a priority signal so the ambulance does not have to stop. Does this across the whole route. A few saved red lights might not sound like a big deal but over a full journey in a busy city that can genuinely cut minutes off the response time. And in this kind of situation minutes are the whole conversation.

D Emergency Status Pipeline

The system tracks the emergency through stages as it progresses. Each one gets logged in real time:

- Requested
- Dispatched
- En Route
- At Scene
- Transporting
- Arrived

Patient sees it. Doctor sees it. Admin sees it. Nobody has to call anyone to find out what is happening — they can just look. That sounds like a small thing but when you are waiting on an ambulance or preparing a hospital bay it actually matters quite a bit to know exactly where things are.

E. Hospital Arrival and Completion

Ambulance reaches the hospital, case gets closed out. Either the patient or the doctor confirms completion on their end. System saves everything — journey

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time, how many times signal preemption fired, response metrics overall.

That data does not just sit there. It can actually be used to figure out what is working and what is not. Where delays are happening, which routes are consistently slower, whether the signal preemption is making the difference it should be. Over enough cases that builds into something worth looking at seriously.

Fig 3.0: Login & Workflow

By integrating *secure authentication, role-based access control, GPS-based navigation, and traffic signal prioritisation*, the SAPS architecture provides a comprehensive framework for improving ambulance mobility in urban environments.

V. COMPARATIVE ANALYSIS

Traditional ambulance systems generally rely on manual coordination and standard navigation tools that do not provide priority access within urban traffic networks. As a result, emergency vehicles frequently encounter delays caused by congestion and signalised intersections. In contrast, the proposed (SAPS) integrates *real-time GPS tracking, intelligent route computation, and traffic signal preemption* to improve ambulance mobility during emergencies. The framework enables coordinated-interaction between patients, doctors, and drivers through a unified digital platform, ensuring faster dispatch and real-time monitoring of ambulance movement. Additionally, the implementation reduces waiting time at intersections and improves overall travel efficiency. Compared to conventional approaches, the proposed system offers improved response coordination, enhanced situational awareness, and reduced ambulance travel delays in densely populated urban environments.

Metric	Conventional Ambulance Systems	Proposed SAPS Framework
Navigation Method	Static navigation or manual route selection	Dynamic GPS-based navigation
Traffic Signal Handling	Standard signal cycles followed	Automated signal preemption
Real-Time Tracking	Limited or unavailable	Continuous GPS tracking
Stakeholder Coordination	Manual communication	Integrated patient–doctor–driver platform
Emergency Monitoring	Limited status visibility	Real-time emergency status pipeline
Traffic Congestion Handling	No adaptive routing	Priority route optimization
Response Time Efficiency	Higher delay probability	Reduced travel time through green corridor
Data Analytics	Minimal operational data	Response metrics and performance monitoring

Fig 4.0: Tabular Comparison

VI. SECURITY CONSIDERATIONS

Security and data integrity are critical in emergency response platforms where sensitive medical and location data may be processed(i.GDPR-COMPLIANCE). The proposed system incorporates multiple safeguards to protect user information and prevent unauthorized access. Secure authentication mechanisms, including *email-based login and session token validation*, ensure that only verified users can access the platform. In addition, role-based access control (RBAC) restricts system functionality by assigning specific permissions to users. Communication between the client interface and backend services is secured through HTTPS encryption, minimizing the risk of data interception during transmission. The platform also implements request validation and rate-limiting techniques to mitigate malicious or excessive access attempts. Since the system relies on real-time location tracking for ambulance navigation, location data is processed within controlled application sessions to maintain user privacy. Collectively, these mechanisms enhance system reliability while ensuring the confidentiality and integrity of emergency response data.

VII. RESULTS AND DISCUSSION

Our Current prototype implementation demonstrates the effectiveness of integrating real-time GPS tracking and traffic signal preemption in emergency conditions. Experimental observations from similar intelligent transportation studies indicate that traffic signals contribute to nearly 68% of urban traffic delays, significantly affecting ambulance response time.

By enabling dynamic communication between the ambulance and traffic infrastructure, the system allows intersections along the route to temporarily provide a green phase, creating a controlled *"green corridor."* Research on emergency vehicle preemption systems shows that such mechanisms can reduce response time by 15–50% and improve travel safetyatintersections.

During prototype testing, the system successfully displayed real-time ambulance location, route progress, and estimated arrival time through an interactive map interface. The integration of priority routing and signal preemption demonstrates the potential to significantly reduce delays caused by congestion and signalized intersections, thereby improving the reliability and efficiency of emergency medical services in urban environments.

VIII.CONCLUSION

How quickly an ambulance gets to someone isn't just a detail—it can decide whether they live or die. Seriously, even waiting a couple of minutes in traffic can make a huge difference. If ambulances show up in under eight minutes, people's chances shoot way up. But every extra minute on the road knocks those odds down about 6%. City traffic and endless stoplights just make things worse. So, here's the fix: a system that uses real-time GPS, smart routes, and even takes charge of traffic lights. Ambulances won't waste precious seconds waiting at red lights or stuck in a line of cars. Research shows this kind of priority can slash response times anywhere from 15% to 50%, even if traffic's a disaster. Mix smart traffic control with digital emergency dispatch, and you get a setup that actually works. It lets ambulances speed through the city and makes emergency services way more reliable..

FUTURE WORK

The system's just getting started. It's moved past the drawing board—it actually works now, but honestly, there's a long road ahead. This is just the first real leap. Now, the plan is to bring in local communities, NGOs, and public health workers, especially where it's tough to get an ambulance. If you've ever been on the ground with people who know their area inside and out, you get it—they help you find the folks who usually get overlooked.

The team's not stopping at version one. They're pushing to make this thing smarter—think AI that spots traffic jams, adjusts routes as the city changes, and figures out on the spot which calls are most urgent. That means help gets there quicker and decisions get sharper when things get messy. The real dream? Opening everything up, running it as a non-profit, and making the system open-source so anyone, anywhere, can shape it to their needs.

But technology has to keep up. They need rock-solid data security for patients, real-time connections with IoT devices, and quicker data analysis to really see what's happening, right as it happens. Building these features out isn't just for show—it lets the system handle bigger emergencies and gets help to the right people, right when they need it. When every second counts, that's the difference.

REFERENCES

[1] Ghosh, Nandi, and Roy (2022) wrote about using PALL systems in emergency medical services. Main thing they focused on was real-time data sharing between people involved in the response. It is a pretty important issue honestly — during emergencies information does not always reach the right people in time and that causes problems. Their work looks at fixing that.

[2] Zhang, Zhao, and Chen (2023) brought 5G into it. They made a framework for allocating ambulance resources more efficiently using 5G.

The concept makes sense. Though in areas where 5G is not even available yet it is hard to see how practical it gets.

[3] Wang, Liu, and Zhang (2023) made a triage model using machine learning to figure out how serious emergency cases are. The point is to help medical staff decide who needs attention first. Staff are usually overworked anyway so something that helps sort that out automatically is useful. Not perfect but useful.

[4] Ramya and others (2022) tracked ambulances in real time using GPS and Android. Simple system. Works. Easy to set up compared to a lot of other proposed solutions. That alone makes it stand out a bit.

[5] Ziliaskopoulos and Mahmassani (1996) is old but still relevant. They worked on route optimization and actually accounted for intersection delays and turn times when calculating travel time. That kind of detail made their results more accurate than a lot of other work from the same period. Still gets cited now.

[6] Li, Wang, and Zhang (2017) did something with traffic signals — made them respond to real traffic data instead of fixed timers. Helps with congestion. For ambulances this kind of thing actually matters because sitting at red lights costs time.

[7] Hulsebosch, van Eeten, and van den Berg (2007) were not really focused on tech. More about coordination between agencies during emergencies. Their whole thing was that smart systems only work if agencies actually work together. Which is obvious when you say it out loud but apparently needs saying.

[8] WHO (2019) put out a document on prehospital trauma care. Global standards basically. More of a reference thing than actual research but good for checking how a system compares to what is internationally expected.

[9] OSRM is just a routing tool. Open source. Used a lot for real-time navigation. Works well which is probably why it keeps getting used in different projects (Project OSRM, 2025).