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Article

Real-Time Medical Emergency Tracker Using GIS and GPS for Optimized Emergency Response

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Abstract: The Medical Emergency Tracker is an advanced geospatial real-time decision support system designed to increase situational awareness, decrease response time, and provide rapid access to critical healthcare infrastructure during acute, life-threatening medical emergencies. The platform is designed to operate under the most time-sensitive conditions, incorporating high-precision GPS localisation, state-of-the-art geographic information systems (GIS), and real-time telemetry data from emergency medical service (EMS) fleets, to offer a comprehensive, context-aware solution for prehospital emergency care coordination. The system, essentially, automatically locates the user's geographic position and algorithmically locates the closest and most appropriate healthcare assets, such as tertiary care hospitals, trauma centers, urgent care facilities, community pharmacies and mobile medical units. Traditional static locator services are not the same. The Medical Emergency Tracker factors in a number of dynamic parameters such as proximity, real-time traffic data, healthcare facility capacity, resource availability, and operational status to deliver accurate, actionable recommendations. The platform's built-in EMS telemetry interface enables real-time display of ambulance availability, location, and operational status, as well as calculation of the estimated time of arrival (ETA) and continuous optimisation of routing decisions based on current traffic conditions and regional resource limitations.

Keywords: Medical Emergency Tracker; Geospatial Decision Support; Geographic Information Systems (GIS); Estimated Time of Arrival (ETA); Emergency Medical Service (EMS).

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1. Introduction

In medical emergencies where time is of the essence, every second counts, as timely access to the right healthcare services can often mean the difference between life and death for the patient [40]. Urban infrastructure is becoming more complex, traffic congestion and uneven distribution of medical facilities make it more difficult to respond to emergencies in a timely manner [31]. In this context, the Medical Emergency Tracker has been developed as an innovative real-time geospatial decision support system to revolutionise emergency care access and delivery [54]. Using a combination of cutting-edge technologies including high-precision GPS localisation, complex geographic information systems, and real-time telemetry of emergency medical services, the platform bridges the crucial gap between patients and healthcare infrastructure [60]. It gives people and health care providers instant, actionable knowledge that can be used to make faster,

better decisions in high-pressure situations [45]. This platform is not a traditional emergency response system that heavily relies on centralised control and limited data inputs, but it is rather a dynamic platform that combines multiple streams of real-time information to provide a comprehensive and context-aware solution.

The Medical Emergency Tracker is based on the ability to detect the geographical location of the user independently and instantly map the most relevant and accessible medical resources nearby [49]. These resources include hospitals, trauma centers, urgent care clinics, pharmacies and even mobile medical vans. The system is not only based on the static proximity calculations, but considers a lot of dynamic parameters such as real time traffic conditions, capacity of the facility, availability of medical resources, operational status of healthcare centers etc [27]. The multi-dimensional analysis ensures users are directed to the most appropriate facility, not the closest one, thus greatly improving the efficiency of the emergency response [57]. Moreover, the implementation of dynamic routing algorithms facilitates ongoing optimisation of travel routes in response to changing road conditions, providing the quickest route to the chosen healthcare destination [36]. Furthermore, the estimated arrival time calculation based on the real time traffic and ambulance fleet data increases the reliability and usability of the system.

Another notable advance in prehospital care coordination has been the incorporation of the platform into telemetry of emergency medical services [42]. The system provides real-time information on the availability of ambulances, their location and operational readiness, allowing for better allocation of emergency resources [61]. This feature is particularly valuable in cases where multiple emergencies happen simultaneously, as it helps dispatch units decide how to appropriately utilise resources. The system's ability to track and predict ambulance movements also ensures patients receive timely assistance, reducing delays that could prove fatal [33]. The integration of user-generated requests and EMS data can be seamless, creating a synchronised environment where all stakeholders are on the same page, resulting in better coordination and improved patient outcomes. Designed to be user-centric, one of the Medical Emergency Tracker's key strengths is its accessibility and ease of use [51]. The platform offers a multi-layered, interactive spatial interface that provides a visually intuitive and information-rich environment to the users. The interface is designed to be usable by professional emergency responders and civilian users alike, and is robust enough to be used in high stress situations.

The system transforms complex data into simple visual elements that are easy to understand, allowing users to quickly identify healthcare facilities near them, evaluate their suitability, and make informed decisions [39]. This level of accessibility is particularly important in emergency situations, where there may be time constraints and emotional distress that can affect decision making [53]. The platform provides clear, concise information that allows users to act quickly and with confidence. The Medical Emergency Tracker improves emergency response times and improves the efficiency and resilience of healthcare systems more generally [30]. Decentralising emergency navigation, the platform lowers dependence on centralised dispatch centers and allows individuals to make proactive efforts in seeking medical care. This is particularly useful in underserved or rural areas that have limited access to emergency services. The system makes it easier for these communities to locate and reach healthcare facilities, improving access to care and reducing disparities [44]. Furthermore, the integration of the platform with public health databases enables authorities to track healthcare utilisation patterns, identify gaps in service delivery and allocate resources more efficiently.

This ability is especially important in large-scale emergencies, such as pandemics, natural disasters, or mass casualty incidents, where the provision of timely and accurate information is critical to an effective response [35]. The benefits of the Medical Emergency Tracker are many and cover many aspects of emergency care. The user-friendly interface enables people with varying levels of technical expertise to find their way around the system with little difficulty [26]. The platform enables better patient results with shortened response times and directs patients to the most appropriate healthcare facilities [55]. The real-time dynamic routing improves the travel efficiency and the integration of

live data guarantees the accuracy and relevance of recommendations. Additionally, the system improves the situational awareness of users and emergency responders by providing a holistic view of the current emergency landscape [48]. Together, these features offer a comprehensive solution that transcends the limitations of existing solutions and establishes a new standard in emergency care coordination.

There are many systems that use geospatial technology to support emergency response, but the current situation is fragmented and incomplete [46]. For example, popular navigation platforms offer basic functions to search nearby hospitals, clinics and pharmacies. These tools are useful for high-level navigation but are missing essential data, such as real-time information on healthcare facility capacity, availability of ambulances, and clinical triage information [29]. This can lead users to facilities that cannot provide immediate care, leading to delays and inefficiencies. Likewise, urban emergency medical services dispatch systems are able to use sophisticated technologies such as computer aided dispatch and automatic vehicle location [38]. However, these systems are most often restricted in scope to internal use by EMS agencies and are not available to the public limiting their potential impact on decentralised decision-making.

Other platforms solve specific parts of emergency response, but not a comprehensive solution [41]. For instance, some mobile applications are intended to notify trained bystanders about nearby cardiac arrest events and the location of automated external defibrillators [58]. These applications do well in terms of fostering community participation, but are limited to certain emergency situations and do not extend to wider healthcare navigation. Similarly, systems that improve the operation of emergency call centers by providing caller profiles and real-time location information improve the communication between users and dispatch centers but do not provide independent decision-support capabilities for users [32]. Health information exchange platforms can provide useful data on hospital capacity and patient routing, especially in public health crises, but often lack user-friendly spatial interfaces and real-time routing capabilities [50]. National triage systems offer a framework for appropriate healthcare pathways, but typically lack geospatial visualisation and real-time data integration.

These limitations highlight the need for a unified platform that combines the advantages of the existing systems while addressing their weaknesses [52]. The Medical Emergency Tracker fulfils this requirement by providing a fully integrated solution that incorporates geospatial intelligence, real-time EMS telemetry, dynamic routing, and public accessibility within a single interface [56]. Together, these components create a holistic platform that allows for efficient and effective management of medical emergencies and allows users to make informed decisions [34]. The integration of such services not only benefits the individual but also improves the performance of healthcare systems through better resource use and reduced inefficiencies. Apart from its utility, the Medical Emergency Tracker has immense implications on the future of healthcare delivery [43]. With advancing technology, the integration of real-time data and advanced analytics will have an increasingly important role in shaping healthcare systems. The platform's capacity to adapt to shifting circumstances and integrate new sources of data means it remains pertinent in a fast-changing environment.

Further, its emphasis on user empowerment and decentralised decision making resonates with broader trends in healthcare that emphasise patient-centered approaches and community engagement [37]. This enables individuals to play an active role in managing their health and thus contributes to a more responsive and resilient healthcare ecosystem." In conclusion, the Medical Emergency Tracker represents a groundbreaking method of handling emergency care, merging cutting-edge technology with user-centric design to deliver a reliable and versatile solution [47]. The ability to provide real-time, context-aware information and facilitate rapid decision making makes it an invaluable tool in time sensitive situations [28]. The Medical Emergency Tracker addresses the shortcomings of current systems by offering a holistic and integrated solution, which can greatly enhance patient outcomes, optimise healthcare system efficiency and ultimately save lives [59]. It establishes a new standard for emergency response systems and opens

the door for a more integrated and effective healthcare infrastructure through ongoing innovation and adaptation.

2. Materials and Methods

Review of Literature

The proposed system Medical Emergency Tracker is a real-time geospatial decision-support system to improve situational awareness and provide rapid access to critical healthcare infrastructure during medical emergencies [11]. The system uses high-accuracy GPS technology combined with advanced Geographic Information Systems to automatically detect the current location of the user and define the best suited healthcare resources nearby. This includes tertiary hospitals, trauma centers, urgent care centers, pharmacies and mobile medical units [2]. The system combines location intelligence and real-time data to not only guide users to the nearest facility, but to the most appropriate facility based on service availability and operational readiness [18]. One key system function is automated health care asset mapping, where nearby medical facilities are algorithmically identified and ranked by distance, real-time capacity, and operational status [15]. This allows users to get accurate and contextualised recommendations in emergencies [23]. Additionally, the system incorporates real-time telemetry data from emergency medical service fleets, enabling users and dispatchers to track the availability, location and readiness of ambulances in real time [7]. This feature enhances coordination between patients and emergency responders, aiding in minimising delays in providing service. Also, the intelligent routing and estimated time of arrival engine leverages the live traffic data and resource availability to determine accurate arrival times and recommend optimised routes thereby minimising response time.

The system also provides an interactive multi-layered spatial interface showing a dynamic map with the necessary information such as healthcare facilities, traffic conditions, ambulance locations and triage recommendations [9]. The interface is designed to allow quick and efficient decision making in stressful situations [22]. The platform also provides context-aware decision support, giving on-the-spot, real-time insights to help both civilians and emergency responders make informed decisions about triage and launch appropriate care in a timely manner [5]. The functional requirements of the system are designed to ensure efficient operation and smooth user interaction. The system incorporates user management features that enable individuals, such as patients, responders, and hospital staff, to register and log in securely [19]. Role-based access control is implemented to differentiate permissions between the administrator, responders, dispatchers, and medical professionals [13]. Users can send emergency alerts, including location, which are automatically prioritised based on the severity of the situation.

There is a panic button incorporated that can be activated quickly using mobile devices or wearable technology. The basic feature is real-time location tracking which allows tracking of patients, ambulances and healthcare facilities continuously by using GPS technology [6]. The route optimisation and traffic-aware estimated time calculation makes sure of efficient navigation. The dispatch system automatically dispatches the nearest available ambulance, and the centralised dashboard enables dispatchers to track ambulances in real time [1]. By integrating with hospital management systems, the platform can retrieve live data about hospital capacity such as availability of emergency beds, intensive care units and ventilators. Based on the patient needs, the platform can recommend the most appropriate healthcare facility [16]. The system also has a communication module that enables patients, responders and healthcare providers to communicate through in-app chat or voice communication [25]. Emergency alerts can be escalated via multiple channels such as SMS, email or push notifications to ensure timely response [10]. Additionally, the system allows for the management of medical records by giving paramedics access to critical patient information, such as medical history and allergies, essential for delivering proper care in emergency situations [21]. These functional features collectively guarantee efficient system performance, catering to the needs of all parties involved in emergency response.

From the point of view of non-functional requirements, the system is designed to provide high performance, scalability, reliability and security [12]. It guarantees rapid response times – emergency alerts processed in less than two seconds and real-time tracking updates delivered every five seconds or less [24]. The system is designed to support a high volume of concurrent users, with thousands of simultaneous requests supported through a scalable microservices architecture [8]. It guarantees high availability and reliability with a 99.99 percent uptime service level agreement and auto-failover mechanisms to avoid critical service disruptions. Security is a top priority with end-to-end encryption of data in transit, and standards for healthcare data protection [17]. Authorisation mechanisms (OAuth, JSON Web Tokens, etc.) are used to protect sensitive information and control access based on role [20]. The system has been designed with usability in mind to make it easy to use, especially for patients who may be under stress in an emergency. The interface is easy to use and has voice activation to improve accessibility [4]. The system is maintainable thanks to its modular codebase, extensive documentation, and strong logging and error reporting capabilities that facilitate debugging and system updates. The system is also very mobile, with web based and mobile application interfaces for Android and iOS as well as cross-platform support for ambulance devices [14]. These non-functional attributes ensure that the Medical Emergency Tracker is not only effective in providing its core functionalities but is also reliable, secure, and adaptable to evolving technological and operational requirements.

Methodology

The Medical Emergency Tracker is a cloud-native web and mobile application powered by real time data streams and advanced geospatial APIs, to help facilitate effective and swift emergency response [74]. The system architecture consists of multiple integrated layers that collaborate to deliver seamless functionality and scalability[63]. At the client level, end-users such as citizens, emergency medical service personnel and hospital staff access the application through mobile platforms (Android and iOS) and web-based interfaces [71]. Cloud load balancer is distributing the load among several application servers [77]. This is to handle the incoming requests in large quantities and also to make the system reliable by increasing redundancy and performance. The application layer is split into frontend and backend parts [66]. The frontend is constructed using modern frameworks such as React.js for web applications and Flutter for mobile applications to guarantee a responsive and user-friendly interface. Backend works on frameworks like Flask or Django REST APIs. They do well on business logic, authentication, and data management.

The system has a secure authentication service that uses OAuth 2.0 and JSON Web Tokens or other platforms such as Firebase or Auth0 for token based authentication and data security [68]. For continuous updates on ambulance locations, hospital capacity, and emergency statuses, a real-time communication layer such as WebSocket or MQTT brokers allows users to have the latest information [73]. The database layer comprises relational database management systems (RDBMS) like PostgreSQL or MySQL, frequently hosted on cloud platforms such as AWS RDS or comparable services, for the purpose of storing and managing structured data [65]. Moreover, a caching mechanism based on Redis is integrated to provide quick access to data that changes frequently, e.g. the current locations of ambulances, to improve performance of the system [81]. The system also offers GIS and mapping services through platforms like Google Maps, Mapbox, or OpenStreetMap. These platforms offer critical features like route planning, real-time location tracking, and geofencing [76]. Additionally, a third-party integration layer allows the platform to connect with hospital databases, government emergency services, and ambulance tracking systems through secure APIs, ensuring smooth data sharing and coordination.

The Medical Emergency Tracker is designed to run in a cloud environment such as AWS, Google Cloud, or Microsoft Azure to provide scalability, flexibility, and high availability [62]. The system utilises managed services such as virtual servers, databases, storage, and serverless functions to achieve better performance and lower maintenance overhead [80]. The system also optionally supports containerisation with Docker, which

allows individual microservices to be packaged and deployed independently of each other. Container orchestration tools (Kubernetes, services such as EKS, GKE, or AKS) are used to manage scaling, resilience, and efficient use of resources across the system [78]. We use a strong CI/CD pipeline to make development and deployment easier. Everything is version-controlled on GitHub or GitLab. Continuous integration is done with GitHub Actions, GitLab CI/CD or Jenkins, which automates things like linting, testing, building frontend and backend portions, and deploying to staging and production environments [70]. Typically, the pipeline includes steps such as code validation, building, deploying to a staging environment for testing and manual approval prior to the final deployment to production, thus ensuring reliability and quality control.

The system functions in a broad spectrum of deployment environments to facilitate development, testing and live operations [67]. The development environment is typically set up locally or with Docker-based setups, allowing the developers to test and change the system efficiently [75]. The staging environment is a cloud copy of the production system which can be used for extensive testing and validation before release [72]. The production environment is a fully scaled, secured and continuously monitored environment that handles real-time user interactions and emergency response. The data flow in the system is a systematic process to guarantee timely and accurate delivery of information [79]. When the user makes an emergency request, the backend processes the request and queries the nearest ambulances and healthcare facilities via the GIS APIs [64]. The frontend is updated in real-time by the WebSocket or MQTT protocols, so users and emergency responders can track the movement of ambulances and the availability of hospitals in real-time. Everything that happens and the interactions are stored in the database and can be displayed on dashboards for monitoring and analysis [69]. This integrated architecture ensures that the Medical Emergency Tracker provides a reliable, efficient and responsive solution to handle medical emergencies.

3. Results and Discussion

Result and Discussions

Medical Emergency Tracker (MET) is an advanced real-time geospatial decision support platform that aims to enhance emergency medical response by reducing delays, optimising navigation, and ensuring patients are directed to the most appropriate healthcare facilities for timely care [85]. The system works well in high-pressure and time sensitive environments and utilises high-precision GPS technology, Geographic Information Systems, and real-time EMS telemetry data. The combination of these technologies provides a complete and coordinated solution for prehospital emergency care, enabling individuals and emergency responders to make informed decisions quickly and effectively [91]. The Medical Emergency Tracker architecture is designed in a modular microservices manner to ensure scalability, flexibility and easy maintenance. The system is developed with a Node.js-based backend and HTML integrated with Node.js for the frontend [98]. The system is hosted on a Windows operating system environment and uses Visual Studio Code for development and deployment.

The web interface is optimised for modern browsers such as Google Chrome and Microsoft Edge and will be available for a wide range of users [102]. The interface is designed to be visually intuitive and user-friendly, featuring a multi-layered spatial layout that helps the user to visualise the nearby healthcare facilities, track the ambulance movement and make timely decisions during emergencies. This design provides ease of use for professional responders and general users alike, even in stressful situations. The Node.js application logic is at the core of the system [84]. It handles core functionalities such as user authentication, geolocation detection, smart routing, and emergency resource matching [108]. When a medical emergency occurs, the system automatically detects the location of the user and evaluates the nearest healthcare facilities including hospitals, trauma centers, and mobile medical units [95]. It takes into account various real time factors like distance, traffic conditions, availability of resources, and operational status of facilities to decide on the most suitable option [105]. The smart routing engine takes this

one step further and uses real-time traffic data and GIS algorithms to find the quickest and most efficient way to get to the healthcare provider you select.

It also considers ambulance availability and road conditions for estimating arrival times, thereby enhancing response efficiency [99]. The real-time EMS telemetry interface is critical for the tracking of ambulance locations, the tracking of their readiness status, and the management of fleet availability [87]. This module utilises technologies such as WebSockets to deliver low-latency communication, real-time updates, and accurate tracking. Moreover, the system has a powerful notification feature that uses services like Twilio or Firebase to notify hospitals and emergency responders of new incidents reported [94]. They can be in the form of push notifications, emails and SMS so that all relevant stakeholders are informed in a timely manner and can respond accordingly.

The backend of the system interacts with a MongoDB database that stores structured and semi-structured data [90]. This includes user profiles, incident reports, EMS fleet details, healthcare facility information, and historical logs. MongoDB is especially well-suited for this use case because of its flexibility and its ability to handle geospatial data, making it possible to store and query location-based data efficiently [107]. The database is organised into collections like Users, Facilities, EMS Units, Incidents and Logs that together support system operation and analytical functions [82]. This data can be used for performance monitoring, trend analysis and future planning of healthcare resources. The Medical Emergency Tracker is deployed on cloud platforms like AWS, Microsoft Azure or Google Cloud Platform for high availability and accessibility [101]. The system leverages containerisation technologies such as Docker to package microservices for efficient deployment and scalability. Continuous Integration and Continuous Deployment pipelines using tools like GitHub Actions make the development process easier by automating testing, building and deploying. Security is an important part of the system.

Features such as HTTPS encryption, authentication using JSON web tokens, and compliance with healthcare data protection regulations ensure the safety and privacy of user data [92]. These features together provide a secure, reliable, and scalable platform for managing real-time emergency situations. The system consists of multiple integrated modules that work together to enable real-time coordination and decision-making during emergencies. The user management module provides secure registration, login, and role-based access control for different types of users, including patients, emergency responders, and hospital staff [86]. The emergency reporting part allows users to quickly report incidents through GPS-enabled forms that automatically capture the location, time and type of emergency [103]. The geolocation and mapping component interacts with mapping services to offer a real-time visualisation of patients, ambulances and healthcare facilities on an interactive interface where users can navigate and assess situations efficiently.

The smart routing and estimated time calculation module calculates the most efficient route from the incident location to an appropriate healthcare facility using live traffic data and road conditions. It continually updates the estimated times of arrival and recommends the best routes to minimise delay [89]. The facility matching and resource allocation module identifies suitable hospitals/medical units based on live data about capacity, resource availability and operational readiness [100]. It also adapts recommendations to changing conditions, so users are always pointed to the best option available. The module of EMS telemetry and fleet management monitors the movement of the ambulance, updates the status and helps to dispatch the nearest available ambulance [96]. It also enables analysis of historic data for performance evaluation and resource management enhancement (Figure 1).

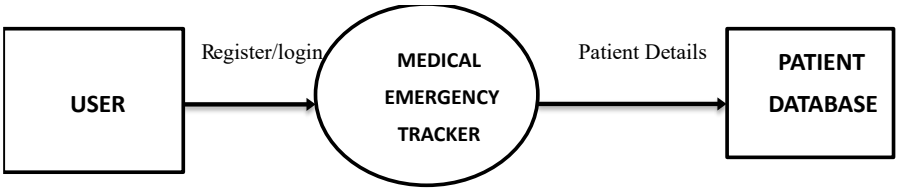

Figure 1: Context-Level Data Flow Diagram (DFD) for the Medical Emergency Tracker System

The system includes a notification and alerting component that provides real-time updates to patients, emergency responders and healthcare providers to enable effective communication between all stakeholders [93]. Updates include incident status, ambulance arrival times, and hospital availability and are delivered by SMS, email or push notification [88]. The data storage and analytics component is an essential part of the system for data management and analysis. It supports geospatial queries and temporal analysis, by using MongoDB, to generate insights for improving the system performance and healthcare planning [106]. It also helps to integrate with the public health systems for wider data sharing and coordination.

The design of the system also utilises database modelling techniques such as entity-relationship diagrams to illustrate relationships between different data entities [104]. The diagrams show the relations between the different components such as users, healthcare facilities, ambulances, and incidents [83]. It helps in visualising the data flow and organization. Data flow diagrams are used to describe the flow of data through the system, focusing on the processes that change data, the locations of data storage, and the interaction between the different components of the system and external entities [97]. Such modelling techniques are essential in the design of an efficient and scalable system, where all the components work together to provide a reliable and effective emergency response solution (Figure 2).

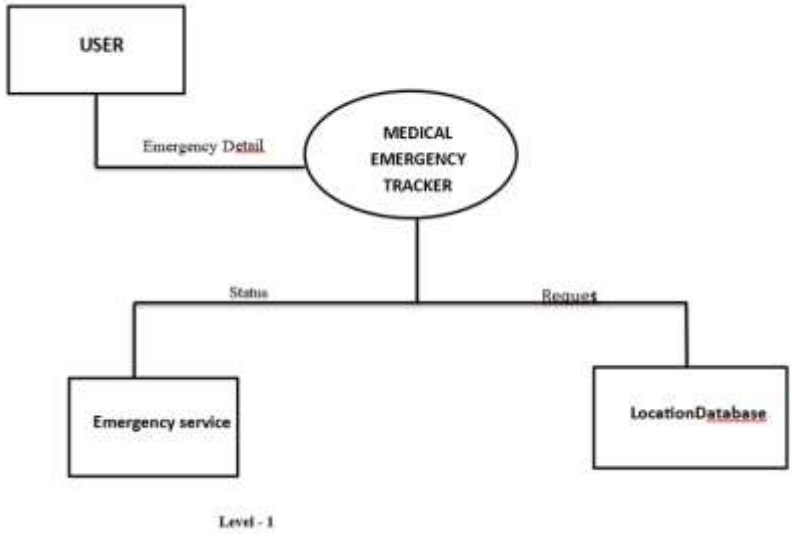

Figure 2: Level 1 Data Flow Diagram (DFD) for the Medical Emergency Tracker System

4. Conclusion

The Medical Emergency Tracker is an innovative and intelligent system that aims to revolutionise disaster and emergency response by integrating real time GPS tracking, patient medical data and emergency resource management. The innovative platform enables faster delivery of care by accurately locating patients and guiding them to the

nearest available medical services like hospitals, clinics, pharmacies, and on-call doctors. The system uses geolocation technology to ensure that people who are in dire need get immediate help, which can be a matter of life and death. The system also allows for quick and easy access to care, as well as improving the efficiency of emergency resource management. It helps first responders, healthcare providers and emergency services better track, deploy and use resources so they can minimise delays and maximise impact. The platform also supports data-driven decision making, enabling authorities to better prioritise action and allocate support in times of crisis. In the future, the system will be significantly improved by artificial intelligence. AI-powered features such as risk prediction, automated triage and intelligent response recommendations will take the system's capabilities even further. The upgrades will not only increase speed and scalability, but will also maximise the effectiveness of emergency response in complex, high-stress environments. Overall, the Medical Emergency Tracker is a major step forward in modern emergency management. Its ongoing development holds out the hope of improved outcomes, reduced mortality and a vital tool for saving lives in day-to-day medical emergencies and mass disasters.

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