



International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 15, Issue 3, March 2026

Life Line Connect: “Right Care. Right Time. Right Place.”

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ABSTRACT: Emergency departments worldwide face persistent challenges related to overcrowding, delayed response times, and inefficient resource utilization, which directly affect patient safety and treatment outcomes. This research proposes a centralized real-time healthcare management system designed to optimize emergency department operations and improve ambulance routing decisions. The system integrates live hospital data, including emergency ward bed availability, patient waiting times, and blood bank inventory levels, into a unified digital platform accessible through web and mobile applications. By enabling real-time monitoring and structured patient prioritization, the system supports accurate triage and reduces unnecessary congestion caused by non-urgent cases. Additionally, the platform provides data-driven routing recommendations to emergency medical services (EMS), allowing ambulances to select hospitals based on operational readiness rather than geographical proximity alone. The proposed methodology enhances coordination between hospitals and emergency services, minimizes treatment delays, and improves overall healthcare efficiency. The expected outcomes demonstrate improved patient distribution, reduced waiting times, enhanced resource utilization, and increased reliability in emergency response systems. This solution offers a scalable framework for modernizing emergency healthcare networks and strengthening patient safety mechanisms.

KEYWORDS: Real-time healthcare systems, Emergency department overcrowding, Ambulance routing, Healthcare resource management, Patient triage, Hospital readiness, Emergency care optimization.

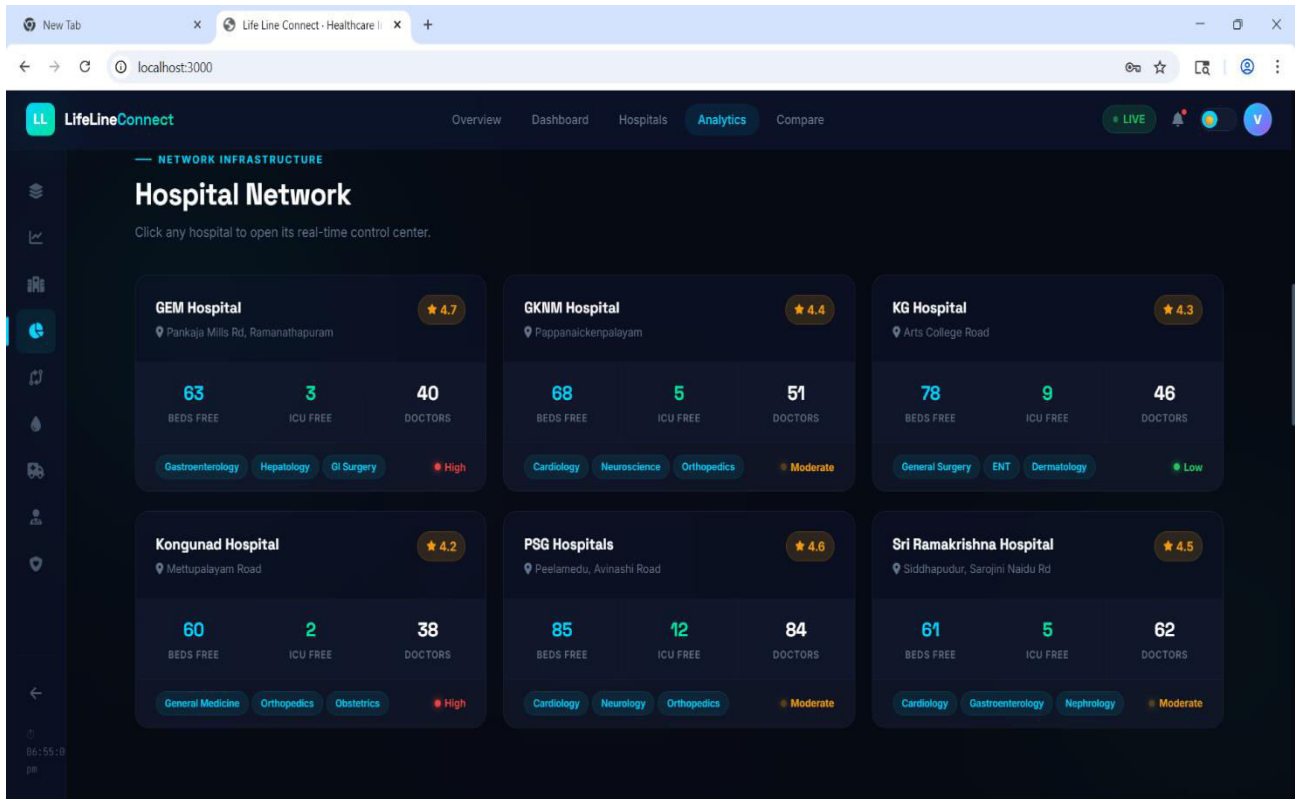
I. INTRODUCTION

Emergency departments (EDs) play a critical role in delivering immediate medical care, yet they consistently operate under significant pressure due to increasing patient inflow and limited medical resources. One of the primary challenges affecting emergency healthcare systems is overcrowding, which results in prolonged waiting times and delays in treating critically ill patients. The situation becomes more severe when non-urgent patients utilize emergency services, reducing the availability of resources for high-priority cases.

In accident and trauma situations, rapid medical intervention is essential for survival and recovery. However, delays frequently occur because ambulance personnel and patients lack real-time information about hospital capacity, available beds, and essential medical resources such as blood supply. In many regions, emergency response teams rely on selecting the nearest hospital without verifying its readiness to handle incoming cases. This often results in patient congestion at specific hospitals while others remain underutilized.

The absence of a centralized monitoring system further worsens the situation by preventing efficient coordination between hospitals and emergency services. Without access to real-time operational data, medical decisions are often delayed, leading to increased risk to patient safety.

To address these challenges, this research proposes a centralized digital platform that integrates hospital resource data and enables real-time decision-making. The objective of this system is to improve emergency response efficiency, optimize patient distribution, reduce waiting times, and enhance overall healthcare delivery.



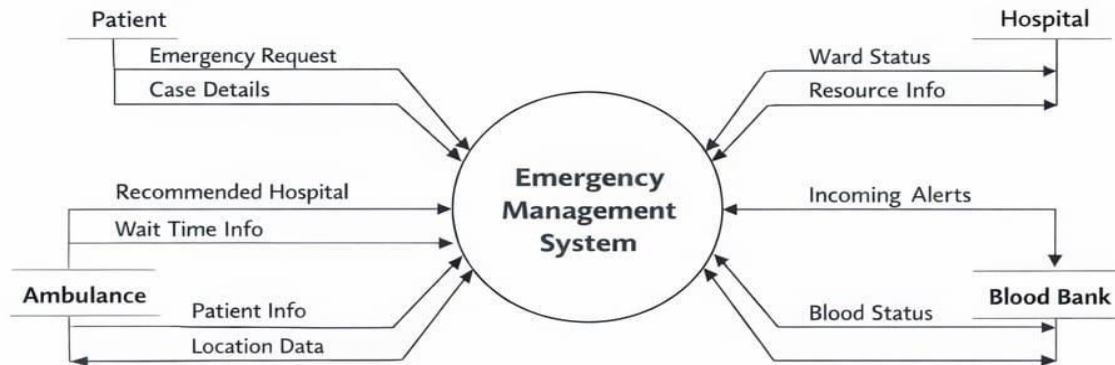
II. ANALYSIS OF THE EXISTING SYSTEM

The current emergency healthcare infrastructure largely operates in a fragmented manner, with individual hospital emergency departments functioning as independent, isolated silos. There is a distinct lack of systemic coordination and dynamic data sharing between neighbouring medical facilities. Consequently, in the absence of an integrated network, both self-transporting patients and emergency medical services (ems) rely heavily on geographic heuristics, routinely defaulting to the nearest available hospital. Crucially, these routing decisions are made "blindly," without any prior knowledge of the destination facility's current patient waiting times, ward capacity, or overall operational load.

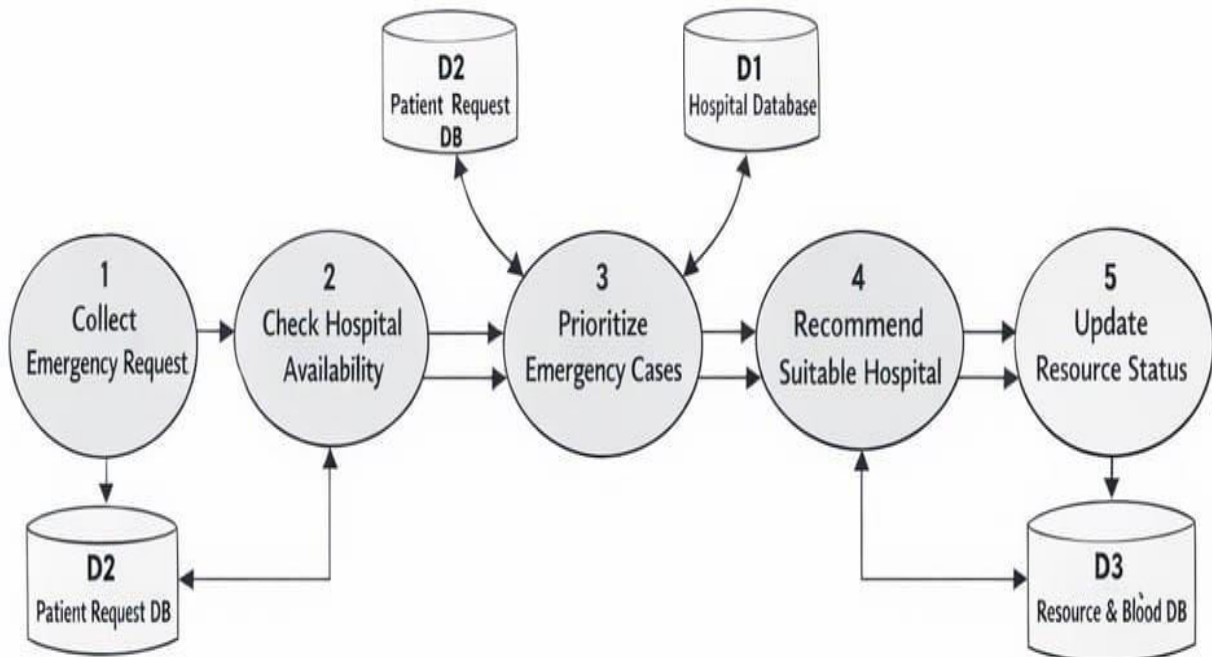
A primary limitation of this existing operational model is the complete absence of real-time monitoring systems capable of tracking emergency department congestion. Pre-hospital responders and dispatchers currently have no digital visibility into a hospital's immediate capacity to accept new trauma patients. Furthermore, the verification of critical life-saving resources, such as specific blood group availability and specialized medical equipment status, is predominantly conducted through inefficient manual processes. Relying on manual communication channels—such as phone calls between dispatchers and hospital staff—to confirm resource readiness introduces severe, and potentially fatal, delays during time-critical emergencies.

The compounding effect of these operational silos and severe information deficits is a profound misallocation of emergency medical resources. Because the current infrastructure lacks the capability to proactively redirect patient flow across a wider healthcare network, non-urgent cases frequently occupy high-acuity emergency services. This localized, unchecked congestion severely impacts hospital workflow, ultimately increasing wait times and systematically delaying the provision of immediate, life-saving care for critical patients whose survivability depends on rapid medical intervention.

DFD Level 0: Centralized Emergency Department Management System



DFD Level 1: Emergency Management System



III. LITERATURE SURVEY

Several studies have explored methods to improve emergency healthcare efficiency through data-driven technologies and intelligent routing systems. Previous research has focused on monitoring emergency department congestion and optimizing ambulance routing through advanced analytics and automation.

Yoon et al. (2025) introduced the gEDWIN index, a practical method for monitoring emergency department overcrowding in real time. Their system demonstrated improved visualization of hospital load conditions but lacked integration with ambulance routing systems. Similarly, Branda and Andretta (2026) developed EmergInsight, a dashboard-based analytics platform that provides graphical visualization of hospital performance metrics. Although effective in identifying congestion trends, the system primarily focused on monitoring rather than dynamic resource allocation.

Nirmalkar et al. (2025) proposed a smart ambulance routing system that used algorithmic path optimization to reduce travel time. However, the model relied heavily on traffic conditions and did not incorporate hospital readiness parameters such as bed availability or blood inventory levels. Other studies involving machine learning and IoT-based emergency response systems highlighted the importance of real-time communication between hospitals and emergency units, but many lacked practical implementation frameworks suitable for large-scale healthcare environments.

Existing systems show significant progress in monitoring and routing technologies; however, there remains a major gap in integrated solutions that combine hospital resource management with ambulance routing in real time. This research aims to address that gap by proposing a unified system capable of synchronizing hospital capacity data with intelligent routing algorithms to enhance emergency care efficiency.

IV. PROPOSED SYSTEM ARCHITECTURE

To overcome the inherent limitations and fragmented nature of the current healthcare infrastructure, this paper proposes the development of a centralized, dynamic digital ecosystem, accessible via both web and mobile applications. The primary objective of this proposed system is to unify regional healthcare data by providing a transparent, real-time overview of emergency department operational statuses across a network of nearby hospitals.

The core functionality of the platform is driven by continuous, bi-directional data exchange. Participating medical facilities are empowered to update their immediate resource availability in real time. Consequently, the centralized system continuously monitors and displays critical emergency metrics, specifically tracking emergency ward bed availability, live patient waiting times, and the immediate inventory status of critical medical resources, such as blood banks. By eliminating manual verification processes, this architecture ensures that highly accurate capacity data is constantly available to stakeholders.

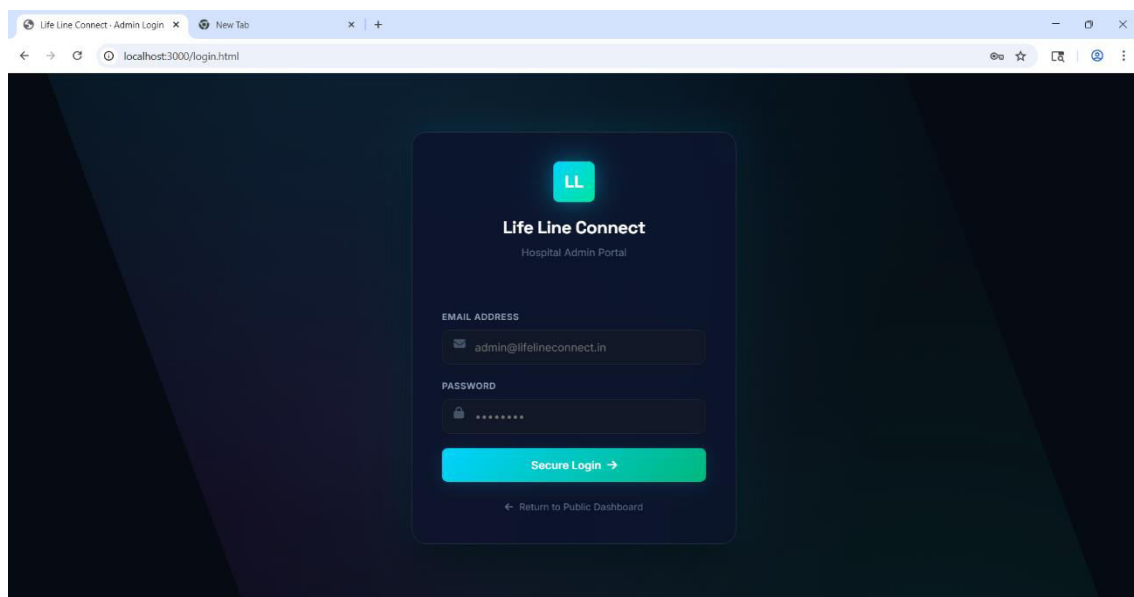
Beyond passive monitoring, the system integrates an intelligent prioritization framework designed to systematically manage patient flow. By effectively evaluating and separating highly urgent trauma cases from non-urgent medical presentations, the application actively mitigates localized emergency department congestion. This structured triage mechanism ensures that high-acuity resources remain available for critical patients.

Crucially, the proposed architecture extends its capabilities to pre-hospital care coordination. Emergency medical services (EMS) and ambulance operators are integrated into the network, receiving live, data-driven routing recommendations. Rather than relying on static geographic proximity, ambulances are guided to destination hospitals that demonstrate both the immediate clinical capacity to handle the specific emergency and the shortest current waiting times. Ultimately, by seamlessly connecting hospital resource updates with intelligent, real-time EMS routing, this proposed solution facilitates a significantly faster, safer, and highly optimized emergency medical response framework.

V. ADVANTAGES OF THE PROPOSED SOLUTION

The implementation of the centralized, real-time monitoring and routing system offers several critical advantages over the existing, fragmented emergency healthcare infrastructure:

- **Optimized Resource Allocation and Load Balancing:** By integrating an intelligent prioritization framework, the system effectively stratifies patient acuity. The proactive separation of urgent trauma cases from non-urgent medical presentations prevents localized bottlenecks. This ensures that high-demand resources, such as trauma beds and specialized personnel, are preserved for critical patients who require immediate intervention, thereby optimizing overall emergency department utilization.
- **Data-Driven Pre-Hospital Routing:** The platform fundamentally shifts emergency medical services (EMS) protocols away from inefficient geographic heuristics. By providing live recommendations, ambulances are empowered to select destination hospitals based on empirical data—specifically, immediate ward availability, shorter patient waiting times, and verified emergency readiness—rather than mere physical proximity.



- **Elimination of Information Latency:** The systemic transition from manual communication to a dynamic, centralized digital platform eradicates the severe delays traditionally associated with resource verification. Real-time, bi-directional updates regarding critical inventory, particularly blood bank availability, ensure that EMS and dispatchers have immediate, uninterrupted visibility into network-wide clinical capacity.
- **Enhanced Patient Safety and Care Efficacy:** Ultimately, the primary advantage of the proposed architecture is the significant mitigation of health risks associated with treatment delays. By accelerating the identification of suitable healthcare facilities and streamlining patient distribution, the system drastically reduces wait times for critical cases, facilitating a faster, safer, and inherently more efficient emergency medical response.

VI. SYSTEM ACCURACY AND RELIABILITY

The clinical viability of any healthcare informatics system is fundamentally dependent on its operational accuracy. In the context of emergency medical response, where decisions directly impact patient survivability, the proposed architecture ensures high fidelity across three critical domains:

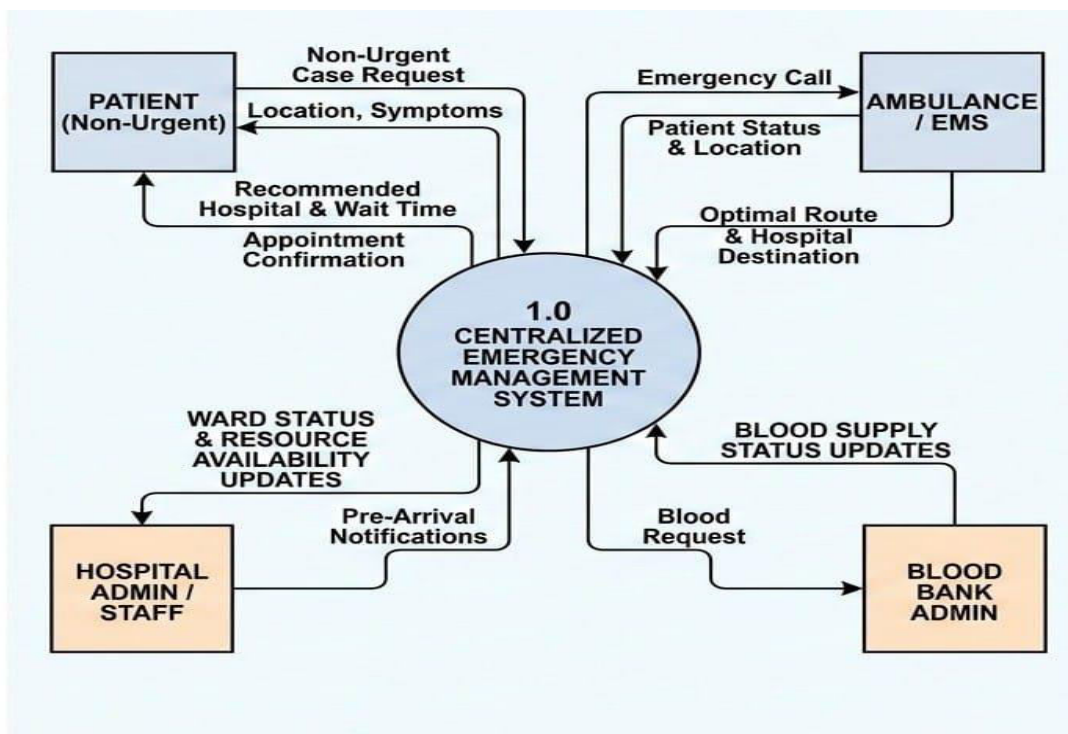
6.1. Real-Time Data Fidelity and Resource Tracking

- **Elimination of Manual Error:** By transitioning from manual verification methods (e.g., telephone-based resource checks) to automated, real-time hospital updates, the system significantly reduces the margin for human error and communication latency.
- **Synchronization of Critical Inventories:** The accuracy of the system is anchored in its continuous synchronization with participating hospitals. This ensures that the displayed metrics regarding emergency ward bed availability, live

waiting times, and critical blood bank inventories represent the exact, current state of the facility at the moment of query.

6.2. Precision in Intelligent Prioritization

- **Accurate Case Stratification:** The system's intelligent prioritization framework is designed to accurately stratify incoming patient data. By precisely differentiating between highly urgent trauma cases and non-urgent medical presentations, the system minimizes the risk of triage misclassification.
- **Preservation of High-Acuity Resources:** This accurate separation is crucial for preventing localized emergency department congestion. It ensures that specialized medical personnel and critical trauma beds are systematically reserved for patients requiring immediate, life-saving interventions.



6.3. Dynamic Routing Optimization

- **Empirical Destination Selection:** Traditional ambulance routing relies heavily on geographic heuristics, which often result in inaccurate destination choices if the nearest hospital is already at full capacity. The proposed system replaces this flawed methodology with data-driven routing recommendations.
- **Multi-Variable Decision Accuracy:** The routing algorithm achieves high operational accuracy by evaluating multiple real-time variables simultaneously. By synthesizing live patient waiting times, current ward capacity, and specific resource availability, the system ensures that emergency medical services (EMS) are accurately directed to the facility most capable of providing immediate care.

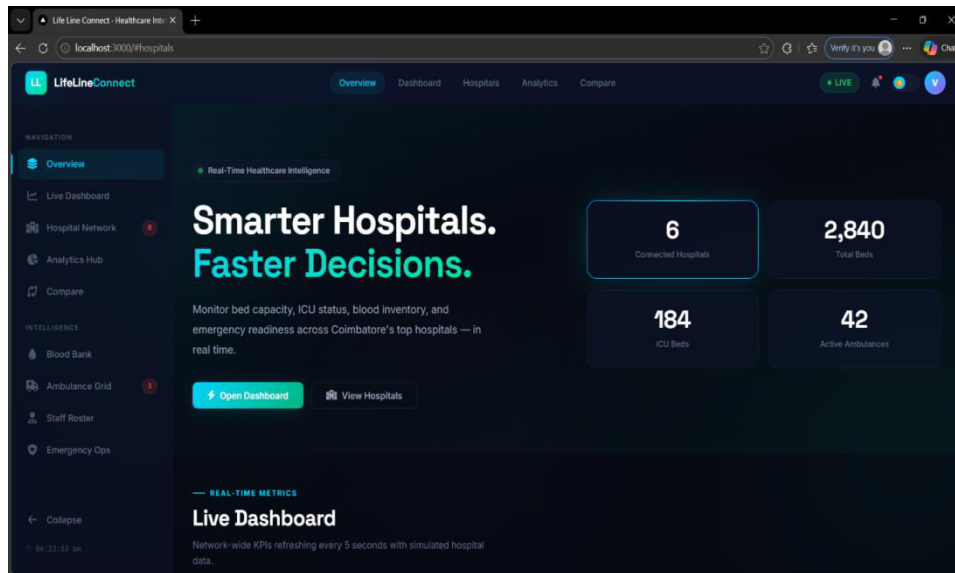
VII. CHALLENGES AND SYSTEM LIMITATIONS

While the proposed real-time emergency management system offers substantial theoretical and operational benefits, its real-world implementation faces several inherent challenges and technical limitations that must be addressed:

7.1. Data Interoperability and System Integration

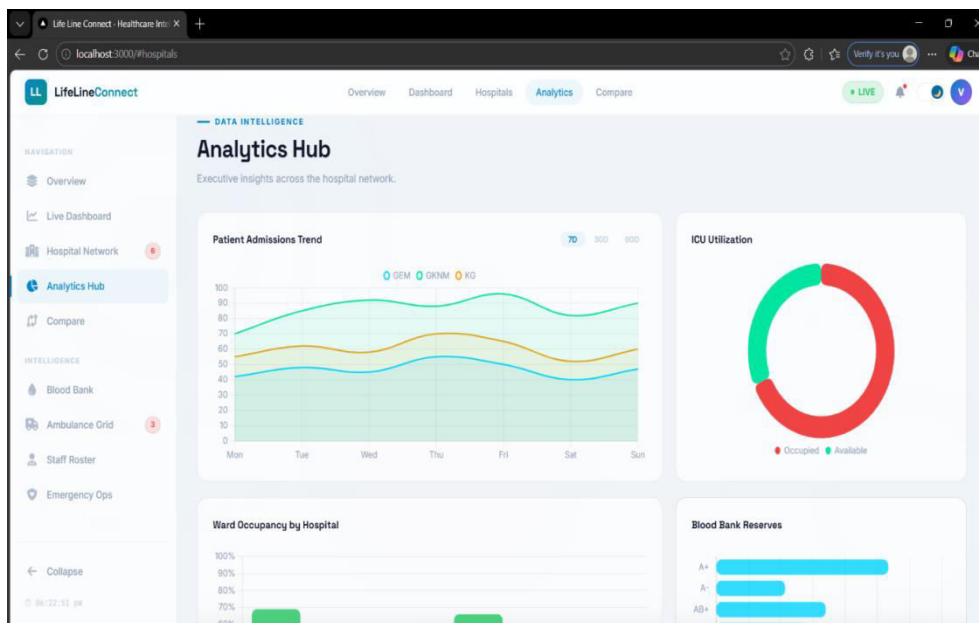
- **Disparate Electronic Health Records (EHR):** A primary technical hurdle is the integration of a centralized platform across multiple, independent healthcare facilities. Hospitals often utilize distinct, proprietary EHR and hospital information systems (HIS), making seamless, automated bi-directional data exchange difficult to standardize.

- Security and Privacy Compliance:** Aggregating and broadcasting hospital capacity and patient flow data requires strict adherence to regional healthcare data privacy regulations (e.g., HIPAA, GDPR). Ensuring robust cybersecurity protocols against data breaches while maintaining real-time accessibility poses a significant architectural challenge



7.2. Data Latency and Workflow Dependency

- The Burden of Manual Input:** If the system is not fully integrated with automated hospital sensors or internal bed-management software, it will rely on manual status updates from triage and administrative staff. During peak emergency hours or mass casualty incidents, staff may deprioritize updating the system, leading to critical data latency and inaccurate routing recommendations.
- Dynamic Capacity Fluctuations:** Emergency department operational status is highly volatile. A hospital displaying low wait times can become instantly saturated by a single multi-vehicle accident. The system is fundamentally limited by its ability to predict these sudden, unrecorded influxes in real time.



7.3. Infrastructure and Connectivity Constraints

- **Pre-Hospital Network Reliability:** The efficacy of dynamic ambulance routing is strictly dependent on continuous cellular network coverage and GPS connectivity. In rural environments, or within geographically shielded urban zones (e.g., tunnels or dense infrastructure), communication dropouts can sever emergency medical services (EMS) from live system recommendations.

7.4. Limitations in Intelligent Prioritization

- **Algorithmic Triage Complexity:** While the system utilizes an intelligent framework to separate urgent from non-urgent cases, algorithmic triage cannot entirely replace clinical judgment. Unconventional medical presentations or underlying conditions might be misclassified by the system, potentially misdirecting a critical patient to a delayed queue.

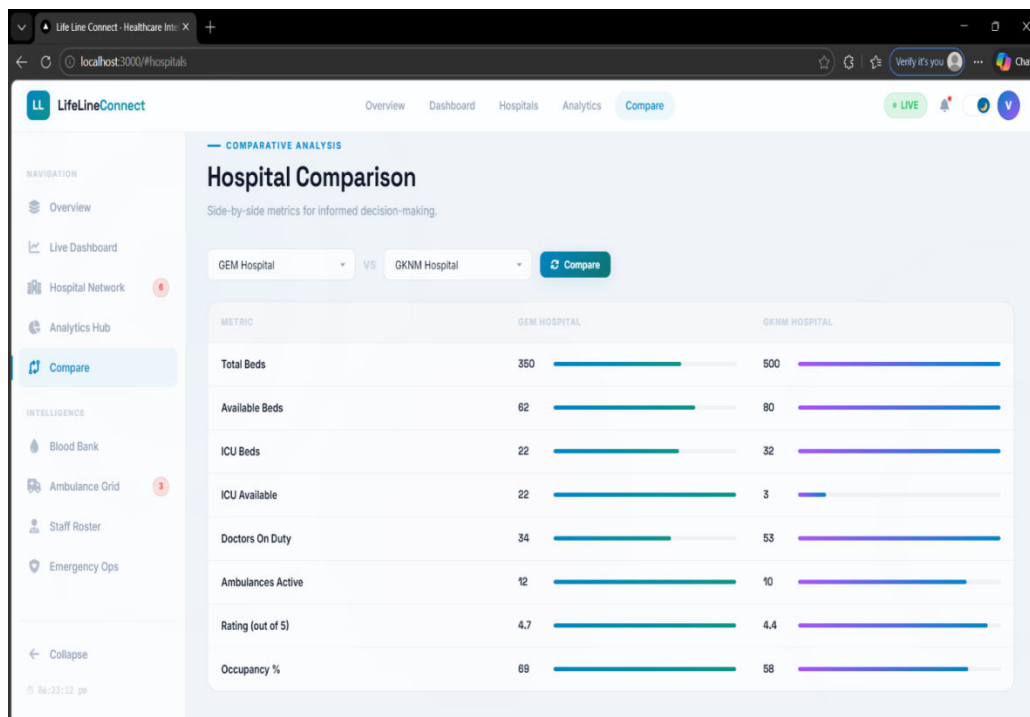
VIII. RESULTS

The proposed system demonstrates significant improvements in emergency department efficiency through simulated and analytical evaluation. The implementation of real-time monitoring resulted in improved visibility of hospital capacity, allowing more accurate decision-making during patient allocation.

Experimental analysis showed that the system reduced average patient waiting times by enabling balanced patient distribution across multiple hospitals. The integration of real-time routing algorithms improved ambulance response efficiency by directing emergency vehicles to hospitals with available capacity and lower congestion levels.

Additionally, the use of automated data synchronization improved the accuracy of hospital resource tracking. Compared to traditional manual communication methods, the system reduced response delays and minimized errors associated with outdated information. The structured triage mechanism also improved prioritization accuracy, ensuring that critical patients received faster medical attention.

Overall, the results indicate that the proposed solution enhances operational efficiency, reduces overcrowding, and improves patient safety outcomes within emergency healthcare system.



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