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Research article

Design of an emergency medical information system for mass gatherings

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A R T I C L E I N F O

Keywords:
Mass gatherings
Emergency medical service system
Prehospital emergency medical service
Evacuation decision

A B S T R A C T

Background: The frequency of mass gatherings is increasing. Such events often involve many people and carry the risk of mass casualty incidents, which require substantial medical resources from various healthcare institutions. The current medical system, while meeting daily needs, struggles to address the demand for a high volume of emergency resources and real-time data exchange.

Objective: The aim of this study was to develop an emergency medical information system for mass gatherings.

Methods: We developed an emergency medical information system for mass gatherings. Based on a unified prehospital and intrahospital emergency data exchange protocol, we can directly standardize medical information data and provide data support for the evacuation decision support algorithms of multiple institutions. Wearable devices, vehicle-mounted devices, video calling systems and surveillance systems are connected to capture real-time scenes.

Results: We constructed the system via mobile applications and online platforms and deployed it in 3 hospitals, 5 ambulances and 17 on-site medical locations. We constructed a set of electronic medical records covering the whole first aid process according to the basic principles of first aid. The simulation results show that the proposed algorithm is suitable for mass gatherings. The overall survival rate of patients can be improved by 5 %, and the average evacuation efficiency of patients can be improved by 50 %. Furthermore, in a real-world environment, this method can ensure patient survival and achieve good convergence.

Conclusions: Our system is capable of providing robust medical information support for emergency medical services during large-scale assembly events, ensuring a visualized full-process emergency response and decision-making for the diversion and subsequent transport of a large patient population.

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1. Introduction

A mass gathering, such as the Olympics and international marathons, is defined by the World Health Organization as a planned or spontaneous event that gathers substantial numbers of attendees who might strain the health planning and response capacities of the host community, city, or country [1]. Furthermore, such gatherings pose inherent risks for mass casualty incidents (MCIs), including fires, terrorist assaults, and stampedes that could precipitate widespread casualties, thereby overtaxing the availability of prehospital emergency medical services [2–6].

The aggregation of individuals at these functions can swiftly deplete medical provisions if a considerable number of individuals succumb to injury or illness. This depletion may subsequently impede the delivery of timely emergency medical assistance to the broader community. During the period from 2013 to 2018, nine significant casualties occurred at such events, causing harm to hundreds or even thousands of people [2]. The excessive dependence of an event on local emergency medical services (EMSs) can undermine its capacity to cater to the general populace, depriving the host community of essential healthcare services [7]. It is thus imperative to efficiently manage the allocation and application of regional medical resources.

In the context of mass gatherings, healthcare professionals face formidable challenges in executing triage, treatment, and documentation for a large influx of patients under time constraints. These challenges are compounded when multiple emergency medical entities employing disparate terminologies for identical medical concepts are involved [3]. Such inconsistencies in medical information and terminology can cause delays or gaps in information exchange during emergency responses. The work of Lynn underscores the limitations inherent in establishing an on-site incident command and a regional emergency operations center and underscores the necessity for well-orchestrated communication networks [8].

In the context of everyday emergency medical services, the current system for transporting patients to care facilities is relatively simple, requiring only information from one or a few nearby hospitals to make a decision for patient transfer. However, during mass gatherings, which involve a high volume of patients and a wide distribution of medical posts and hospitals providing medical services, there is a noticeable lack of coordination between emergency services and various hospitals. This disconnect stems from the operation of various emergency medical institutions without a centralized coordination and communication mechanism. The current emergency medical service system lacks the necessary information infrastructure to support its needs and is deficient in an emergency medical service information system that can acquire, store, and share medical information, especially in the event of large-scale casualties. Lin Du advocated for the establishment of an interconnected and intelligent regional collaborative diagnosis and treatment system, which would be facilitated through the sharing and interaction of medical resources within a region [9], thereby expediting the provision of critical care pathways for patients in urgent need.

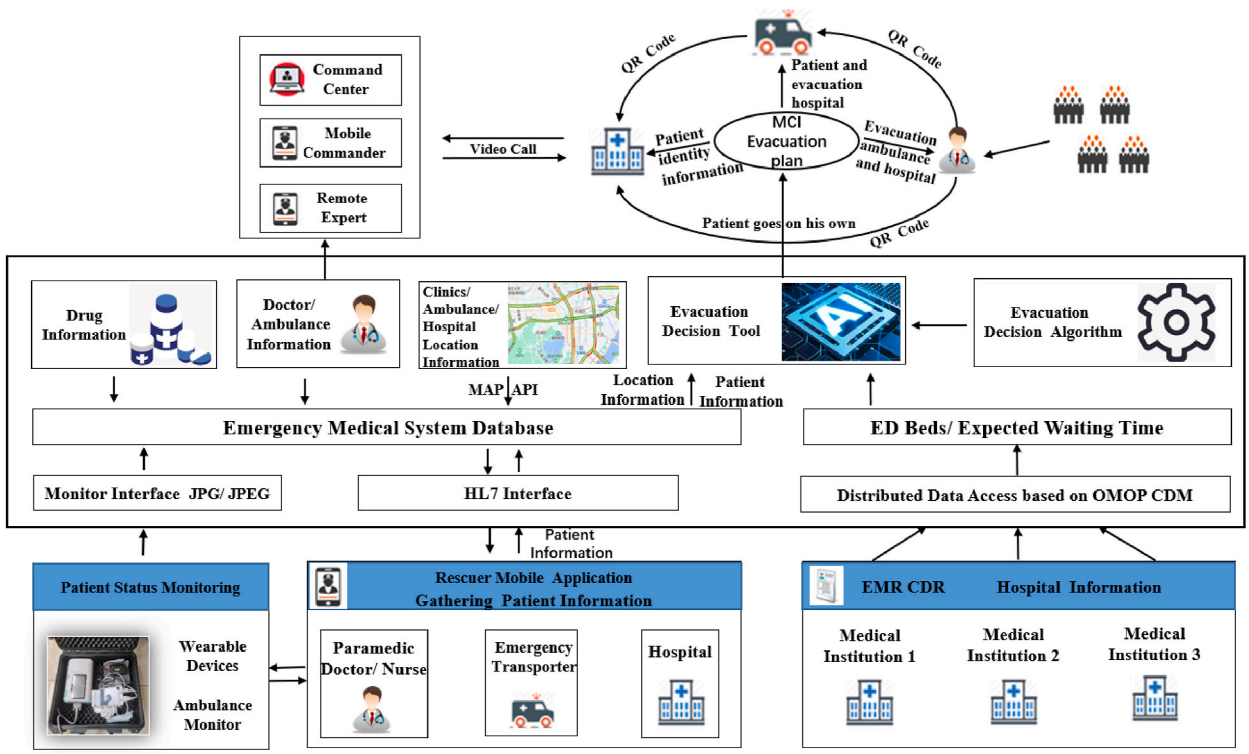


Fig. 1. System architecture diagram.
OMOP CDM: Observational Medical Outcomes Partnership Common Data Model; EMR: Emergency Medical Records; HL7: Health level 7; API: Application Programming Interface; MCI: Mass Casualty Incident; CDR: Clinical Data Repository; ED: Emergency Department.

Moreover, it has been established that the presence of prehospital care leads to a 25 % reduction in trauma-related mortality, a figure that significantly increases when combined with the timely conveyance of patients to emergency facilities where prompt care can be administered [10]. Consequently, an effective emergency medical services system tailored for mass gatherings must not only be equipped to address routine needs but also possess the capacity to efficiently manage and evacuate casualties during emergencies, which imposes a greater logistical challenge.

In summary, the orchestration of large-scale events necessitates extensive provision for on-site emergency care, data sharing, crowd dispersion and transport logistics, as well as unified leadership. Orchestrating emergency medical responses for such events mandates a synergistic effort among various agencies, entailing intricate system design [11–16]. The Chicago Marathon in Illinois, USA, devised a predictive model for medical needs by analyzing geographic, temporal, and diagnostic data from a five-year period, which assisted in the strategic allocation and timing of medical assets and personnel [7]. In 2015, Kumbh Mela benefited from stringent monitoring and continuous assessment of crowd dynamics, which significantly reduced the likelihood of crush injuries, stampedes, and mass casualty events such as fires. Planning and coordination with different akharas (religious groups) to schedule the sequence of holy dips substantially decreased the fatality count from stampedes to 37 in 2015, a stark contrast to the 500 deaths in 1954 [2]. Nevertheless, these strategies are tailored to specific events based on historical data and do not present a universal approach for managing mass gatherings. The aim of this research was to introduce a comprehensive emergency medical information system tailored for large public events, facilitating a collaborative, multicenter approach that caters to the intricate emergency medical requirements of such gatherings.

This paper is organized as follows: The proposed system architecture and the evacuation mathematical model are introduced in Section 2. Section 3 presents the final results of the system and the simulation experiments. Section 4 compares the system proposed in this paper and previous works and discusses the limitations and future directions for research. Section 5 presents concluding remarks.

2. Materials and methods

2.1. Architecture of the EMS information system for mass gathering

Our proposed emergency medical service system for large-scale gathering events is designed to provide coverage for the entire emergency medical service process, from on-site medical points to ambulances and ultimately to hospital treatment. Therefore, employing a multicenter approach, we constructed a three-dimensional system architecture, as illustrated in Fig. 1, which includes a mobile application comprising on-site first aid teams, transport teams, remote expert groups, hospital groups, and command units, as well as a remote command platform. The primary objective of the system is the secure acquisition, exchange, and analysis of various types and sources of emergency medical service data related to large-scale events, encompassing the entire emergency aid process across multiple scenarios and temporal-spatial dimensions of such events. Serving as a conduit for data flow, the system also performs further statistical analysis of the data, providing comprehensive and robust data support for real-time allocation of medical resources during major gatherings and for decision-making regarding evacuation in the event of large-scale casualties.

The ultimate service targets of the emergency medical services system are always the patients, and we need to acquire comprehensive, real-time patient data as much as possible. Therefore, we collected spatiotemporal data on various types of physiological information throughout the emergency care process for patients using wearable devices. Emergency personnel use mobile terminals on site to complete the electronic medical records of patients, record their vital signs, and assess their injuries through structured input. When patients are in transit or arrive at the hospital, medical staff will supplement the electronic medical records to complete the entire emergency care process. The aforementioned information can be synchronized to our emergency command platform for further categorization and analysis. Our goal is to send the analysis results of individual patients and the medical supply and demand situation within the region to the commanders. Consequently, we have designed mobile terminals specifically for commanders and remote experts; they can view real-time patient data on their respective terminals but cannot manipulate the information. To enhance the experience of commanders and remote doctors, we equip on-site doctors with augmented reality (AR) glasses, providing better visual effects to remote experts via the 5G network.

At the data transmission level, we constructed an emergency data transmission line using the HL7 messaging mechanism, which allows seamless data transfer between two mobile terminals and between mobile terminals and the emergency command platform. These data are ultimately stored in our database. Our system includes an evacuation decision-making tool geared toward potential mass casualty events, which can provide recommendations for personalized evacuation decisions based on the injuries of patients, hospital capacity, and real-time traffic information. As all this information is obtained from different medical institutions and even related departments, we adopted a distributed approach, innovating emergency data acquisition from multiple institutions based on the Observational Medical Outcomes Partnership Common Data Model (OMOP CDM). In this way, data of various forms from different hospitals do not need to enter our database, but we can still utilize these standardized data. Moreover, in the face of large-scale casualty events, our decision tool outputs an evacuation decision plan. These types of evacuation decisions are sent to the mobile terminals of emergency personnel, hospitals, and vehicles.

2.2. Evacuation decision for MCIs at mass gatherings

Another goal of this system is to develop an evacuation decision that is suitable for mass gatherings. Unlike the on-site environment of regular emergency medical services, mass casualty incidents at mass gatherings present a scenario in which patients continuously emerge and their numbers surge, whereas the severity of their conditions varies. Due to the difficulty of a single medical institution managing the volume of patients alone, it is necessary to perform rapid diagnostics on the patients, followed by logical triage, and then select the appropriate hospitals based on the availability of medical resources. Considering that the number of ambulances is often substantially less than the total number of patients and that ambulances may sometimes carry two individuals but can only transport them to one hospital, it is imperative that we identify combinations of patients to be conveyed to healthcare facilities. Therefore, we need to attain a balance between the transport capacity of a vehicle and the overall anticipated severity of patient injuries.

In this method, we used the RPM to evaluate the injury status of patients. The rapid RPM injury score developed by Sacco et al. (2005) is based on the respiratory rate, pulse rate, and motor response [17]. The RPM decreases over time, and the lower the initial score is, the faster it decays with time. The RPM is an integer ranging from 0 to 12, with lower numbers indicating more severe injuries and a lower probability of survival. Each patient is assigned an RPM at the start of the simulation based on the set injury severity ratio. However, the RPM decreases as the patient waits on the scene, during the transport process, and while waiting for treatment at the hospital, with delays in these stages leading to a decrease in the score. Importantly, the lower the RPM is, the faster it declines over time. Thus, we established the variation in the RPM over time (every 30 min).

In the evacuation casualty screening process, the screening is conducted when emergency vehicles are available on the scene. According to the principle of critical priority, the selection of casualties does not exceed the carrying capacity of existing vehicles. The time needed for a patient to be sent to different hospitals can be considered the sum of the on-site waiting time, transit time, and hospital waiting time based on the total time for a patient to receive treatment. We obtained the RPM a_{ij} of the patient at the time of treatment.

The overall evacuation decision can be regarded as an optimal solution problem, with the goal of obtaining the solution with the largest overall RPM. The higher the score is, the better the condition of the injured person when they arrive at the hospital to start treatment, the shorter the treatment time they need, the greater the number of wounded people who can be treated in the same hospital, and therefore, the higher the overall survival rate. For this purpose, we establish the following parameter matrix Equation (1):

$$\begin{bmatrix} x_{11}a_{11} & x_{12}a_{12}\cdots & x_{1j}a_{1j} \\ \vdots & \ddots & \vdots \\ x_{i1}a_{i1} & x_{i2}a_{i2}\cdots & x_{ij}a_{ij} \end{bmatrix} \tag{1}$$

where x_{ij} has a value of 0 or 1. When using a value of 1, wounded person i is assigned to hospital j; that is, a_{ij} is selected at this time. x_{ij} is 0, which means no hospital, and a_{ij} is not selected.

The objective function and constraint conditions of the optimization problem are expressed as follows, as shown in Equation (2) and Equation (3):

Objective function:

$$(\max)\mathrm{y} = \sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij}a_{ij} \tag{2}$$

Constraint conditions:

$$x_{ij} \in \{0,1\}(\forall i \in [1,m], \forall j \in [1,n]) \tag{3}$$

$$\sum_{j=1}^{n} x_{ij} = 1(\forall\ i \in [1,m]) \tag{4}$$

$$\sum_{j=1}^{n} Ceil\left(\frac{\sum_{i=1}^{m} x_{ij}}{b}\right) \le c \tag{5}$$

Variable definitions:

m: number of patients; n: number of hospitals

$x_{ij} = 1$: Patient i was sent to hospital j

a_{ij} : RPM of patient i at hospital j

b: ambulance carrying capacity

c: number of available ambulances.

Equation (3) indicates that for any given element in the matrix, its value can only be 0 or 1. Equation (4) specifies that the sum of any horizontal row in the matrix must be 1, signifying that an injured person can only be sent to one hospital. Equation (5) states that the sum of the number of ambulances dispatched to each hospital should not exceed the total number of available ambulances. Here, *Ceil* represents the ceiling function, which uses the smallest integer greater than a number. Within the genetic algorithm, we incorporated several constraints and further transformed these constraints:

$$A^{*}x \le b \tag{6}$$

$$Aeq*x \leq beq \tag{7}$$

$$C(x) \leq 0 \tag{8}$$

$$Ceq(x) \leq 0 \tag{9}$$

$$lb \leq x \leq ub \tag{10}$$

Equation (6) represents linear inequality constraints, (7) represents linear equality constraints, (8) represents nonlinear inequality constraints, (9) represents nonlinear equality constraints, and (10) represents boundary conditions. Here, x is a row matrix of independent variables; A, b, Aeq, Beq, lb, and ub are real matrices of corresponding dimensions; and C and Ceq are nonlinear continuous functions, with lb being a matrix of all zeros and ub being a matrix of all zeros.

Equation (4) refers to m equations summing to 1; this constraint is transformed into the form of Equation (11):

$$0.9 \leq x_{i1} + x_{i2} + \cdots + x_{ij} \leq 1.1 \tag{11}$$

By making a slight modification to Equation (11), it is easy to derive the specific forms of A and b in the corresponding Equation (12). Here, we use m = 2 and n = 3 as an example.

$$A = \begin{bmatrix} 1,1,1,0,0,0 \\ 0,0,0,1,1,1 \\ -1,-1,-1,0,0,00,0,0,-1,-1,-1 \end{bmatrix}, b = \begin{bmatrix} 1.1 \\ 1.1 \\ -0.9 \\ -0.9 \end{bmatrix} \tag{12}$$

$$x = [x_{11}, x_{12}, x_{13}, x_{21}, x_{22}, x_{23}] \tag{13}$$

The ceiling function, as a type of step function, is discontinuous and has points where it is not differentiable; hence, it cannot be directly transformed into standardized constraint conditions for solving. Therefore, this paper proposes an approximation function for the ceiling function, as shown in Equation (14).

$$y = \sum_{n=0}^{\infty} \frac{1}{1 + e^{-20*(x-n-0.1)}} - 0.2 \tag{14}$$

Fig. 2. System platform and the application of the system in the whole process of EMS.
The left side of the figure is the navigation bar, which successively includes the home page, data cockpit, video communication, live picture, simulation result of the emergency plan and background information management.

Using Equation (13), we can transform Equation (5) into a nonlinear inequality constraint with Equation (8). After converting the constraints of our optimization goal into standard constraints, the optimization problem can be solved using the genetic algorithm in MATLAB.

3. Results

3.1. System application

The proposed system was deployed in the emergency medical service of the Sixth World Internet Conference. The mobile application is assigned to 17 on-site medical sites, five ambulances and three hospitals for a total of 39 medical staff members. Fig. 2 illustrates the authentic operational scenario from patient reception to subsequent patient transfer by emergency medical practitioners utilizing our system. On-site physicians initially assess a patient using a portable electrocardiogram (ECG) device, among other instruments, and then record the patient's data via voice or manual entry into a bespoke Android-based mobile application that is exclusive to medical professionals. These data are immediately entered into our database and can be viewed in real time on the platform or through the mobile application dedicated to command personnel, thereby achieving instantaneous sharing of medical information among various staff members within the large-scale event medical system and circumventing decision-making issues caused by information delays.

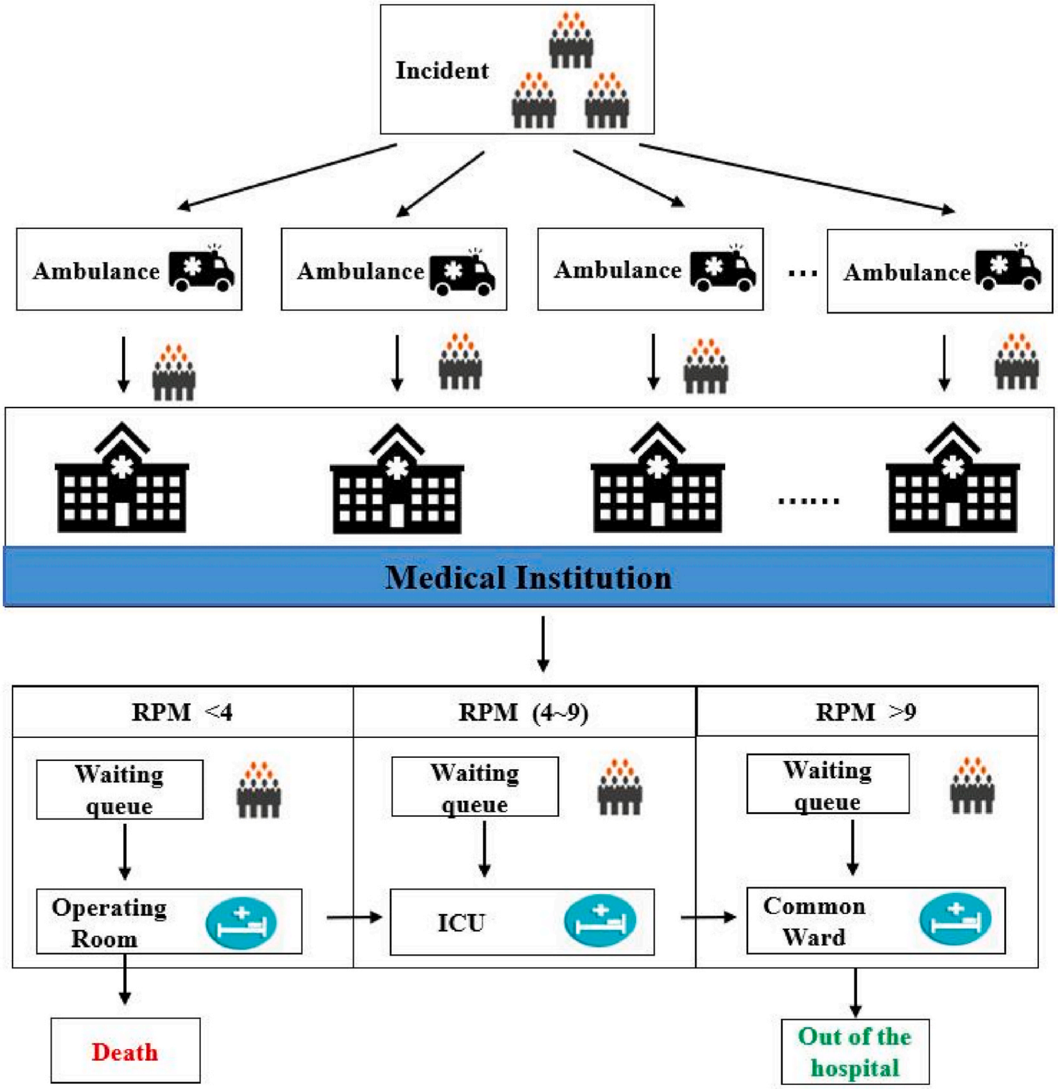


Fig. 3. Simulation process.

After the on-site physician completes the procedure, the application generates a QR code that encapsulates the basic information of the patient, facilitating patient transfer between the site, ambulance, and hospital while preventing erroneous transfer operations. Moreover, we installed panoramic cameras at on-site medical stations, in ambulances, and in the emergency rooms of hospitals, establishing a visual system that encompasses the entire emergency process. To monitor the physiological state of patients in real-time, we stream the ECG monitors of critical patients on the platform, and this live footage can be viewed on the real-time display interface of our platform, as shown in Fig. 2.

The platform's paramount value lies in our ability to garner emergency medical service-related information, such as medical resource details, bed availability, and medication usage, from different hospitals and medical stations. This information enables us to adjust personnel arrangements and resource deployment on the fly during large-scale gatherings and, when needed, facilitates the establishment of real-time video communication between the site, command center, and hospital through the platform, ensuring the rationality and immediacy of patient transfer. The process also allows the receiving hospital to be preinformed about the patient's condition, thereby better preparing for their arrival. For a detailed walkthrough of the mobile application's operation and the interface information on the platform, please refer to the supplementary materials.

After the Sixth World Internet Conference, we ensured the smooth holding of the Zhejiang Merchants Conference. Our system was widely used in the emergency medical service work of the Hangzhou Asian Games in 2022. The system has been used in three Asian Games test events, providing services to 80 medical staff, treating more than 120 patients and providing a data basis for COVID-19 prevention and control.

3.2. Simulation results of the evacuation algorithm

Due to the absence of sudden large-scale casualty incidents in actual application and because almost no patients required further treatment at hospitals, we verified the methods designed for mass casualty events through random controlled simulation experiments. We simulated the entire patient triage process from the scene to discharge, as shown in Fig. 3. In terms of patient numbers, we referred to attendance at a large-scale public gathering and differentiated between regular medical needs and those of sudden mass casualty events by altering the total number of patients at the scene and the attributes of the ambulances.

Moreover, we established four evacuation decision models to simulate the existing ambulance transport methods and designed five scenarios that correspond to the general patient volume at large gatherings and the patient volume in mass casualty incidents. Table 1 details the four different transportation methods and the design of the five scenarios.

Table 2 shows the results for the 5 scenarios. The experimental results indicate that in scenario 1, there was no substantial difference in the survival rates of patients for the four methods, and all the survival rates remained at a high level compared with those in scenarios 2, 3, 4 and 5, which can be regarded as a routine situation.

Fig. 4a shows that by keeping the number and speed of ambulances constant, our model can meet not only typical needs but also the needs of sudden major casualty events. The survival rates of our model are considerably greater than those of the other models, and the difference increases as the number of casualties increases. Especially under resource constraints, we can improve survival rates in patient populations by an average of approximately 5 %. Fig. 4b shows that in the case of adequate vehicle resources, there is still no substantial difference in the results of several methods, which proves that as more ambulances are available to transport patients, a greater daily workload can be accommodated. Table 2 and Fig. 4c simultaneously show the casualty evacuation rates for five conditions. For scenarios 2, 3, 4 and 5, the evacuation efficiency of our model is substantially better than that of the other models. Especially in scenarios 3 and 5, our model did not completely evacuate patients at the end of the experiment, but we improved the evacuation efficiency by approximately 50 % on average. Scenario 4 is close to a typical situation, and all patients can be quickly and efficiently evacuated to the hospital.

This simulation experiment proves that our method can effectively improve the survival rate of patients and the evacuation rate in the face of sudden mass casualty incidents.

Table 1

Detailed descriptions of the four evacuation decision models and five simulation scenarios.

Model 1	Our decision model		
Model 2	According to the priority principle for serious injuries, people with serious injuries should be sent to the hospital with the most remaining resources.		
Model 3	According to the priority principle for serious injuries, people with serious injuries should be sent to the medical institution with the shortest waiting time.		
Model 4	Control group: the patients were triaged and then randomly sent away.		
Scenario (Resource stress)	**Number of patients**	**Number of ambulances**	**Ambulance speed**
Scenario 1	50	9	2
Scenario 2 (abundant resources)	150	9	2
Scenario 3 (extremely tight resources)	300	9	2
Scenario 4 (relatively abundant resources)	150	13	2
Scenario 5 (extremely tight resources)	150	9	1

Table 2
Simulation of the results from Model 1, Model 2, Model 3 and Model 4 in five scenarios (with a single run time of 600 s).

Model	n	Survival rate Mean ± SD	P value	Evacuation rate (200 s)
Scenario 1			Compared with Model 1	
Model 1	100	0.6809 ± 0.0104		100 %
Model 2	100	0.6696 ± 0.0133	0.1741	100 %
Model 3	100	0.6666 ± 0.0123	0.1304	100 %
Model 4	100	0.6752 ± 0.0135	0.7435	100 %
Scenario 2				
Model 1	100	0.5757 ± 0.0092		100 %
Model 2	100	0.5279 ± 0.0090	$1.74\ e^{-6}$	81.2 %
Model 3	100	0.5315 ± 0.0084	$1.05\ e^{-6}$	61.55 %
Model 4	100	0.5433 ± 0.0096	0.00036	65.37 %
Scenario 3				
Model 1	100	0.4684 ± 0.0051		99.52 %
Model 2	100	0.4112 ± 0.0058	$2.29\ e^{-5}$	50.38 %
Model 3	100	0.3718 ± 0.0059	$5.51\ e^{-11}$	51.40 %
Model 4	100	0.4151 ± 0.0068	$1.50\ e^{-5}$	55.37 %
Scenario 4				
Model 1	100	0.5846 ± 0.0059		100 %
Model 2	100	0.5754 ± 0.0089	0.2819	99.66 %
Model 3	100	0.5815 ± 0.0087	0.1621	98.56 %
Model 4	100	0.5815 ± 0.0086	0.1844	99.35 %
Scenario 5				
Model 1	100	0.4503 ± 0.0041		85.95 %
Model 2	100	0.3728 ± 0.0099	$1.17\ e^{-13}$	21.20 %
Model 3	100	0.4499 ± 0.0082	0.1744	21.15 %
Model 4	100	0.367 ± 0.0089	$2.47\ e^{-16}$	48.73 %

3.3. Practice of the evacuation algorithm

On the basis of the hospitals participating in the Sixth World Internet Conference, we quantify the treatment capacity of three hospitals, as shown in Table 3, and based on the real geographic information of their locations, we conduct simulations to further evaluate the reliability of the system and the evacuation algorithm for possible mass casualty events.

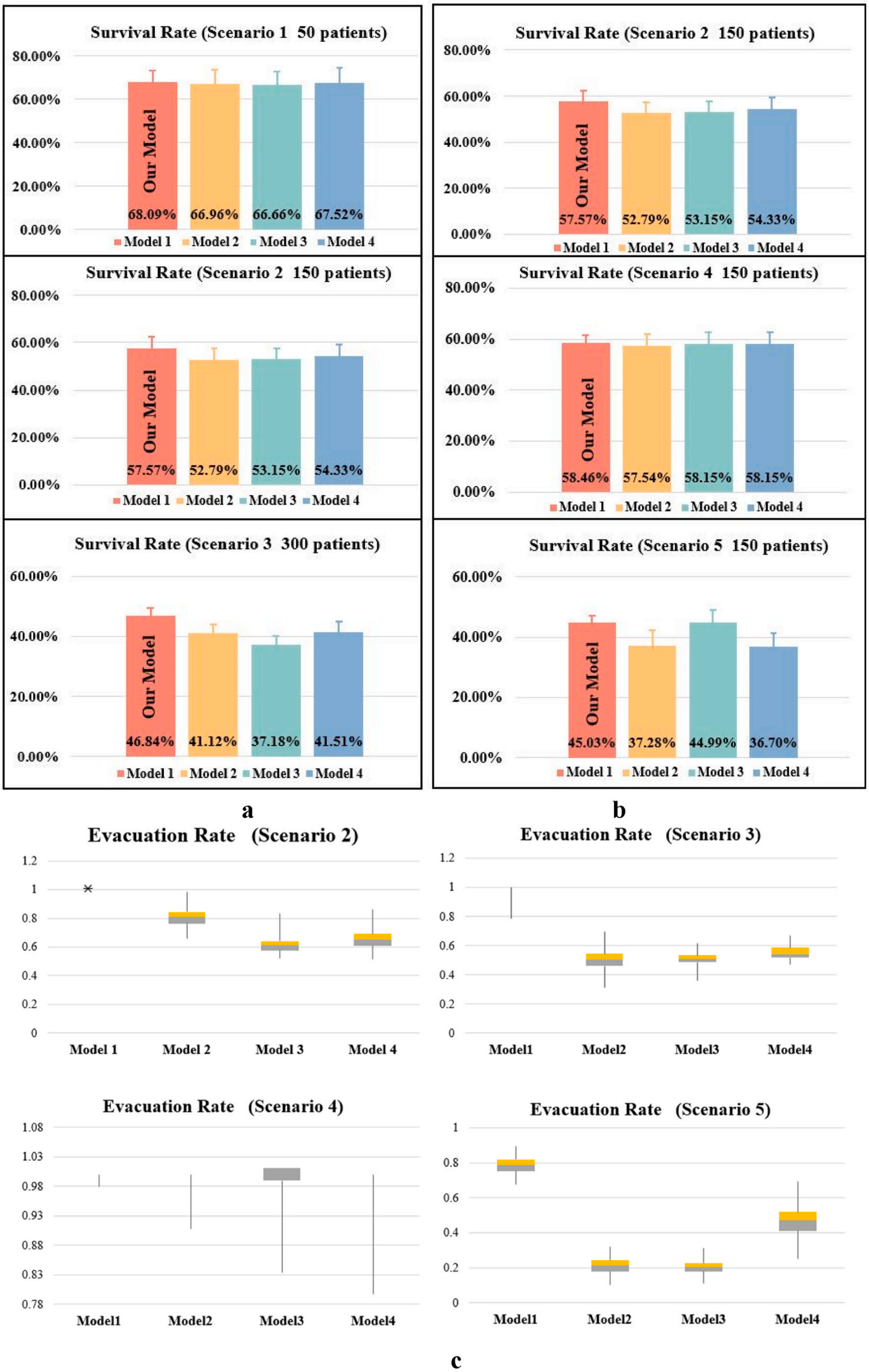
As shown in Fig. 5, our model achieves a substantial improvement over Model 2 because many patients are sent to the farthest Second Affiliated Hospital of Zhejiang University Medical College in the later stage of the evacuation in Model 2, which is obviously unreasonable. In other words, our model meets the requirements of hierarchical diagnosis and treatment on the premise of ensuring overall survival.

4. Discussion

4.1. Principal findings

Given the differing needs between routine prehospital EMSs and those required for mass gathering emergencies, particularly regarding the gap in medical data requirements, the current emergency medical services system lacks the capability to acquire diverse types of medical data from multiple medical institutions. Moreover, there is a deficiency in patient data for prehospital EMSs, resulting in the inability to provide a full process visualization of patient information. In response, we developed an emergency medical services information system for large-scale gathering events. The system is designed to meet the needs of such events by facilitating emergency medical data exchange, providing comprehensive emergency medical service coverage, and enhancing decision-making for mass casualty event responses.

The exchange of information is crucial during the deployment of systems. Chantamunee and colleagues have enhanced the flow of data among participants in prehospital emergency medical services, enabling the system to communicate the ongoing status of rescue efforts to patients in emergency situations [18]. Our team has developed a comprehensive electronic medical records system that is tailored for the management of emergency medical care during mass gatherings, beginning with individual patient care. By utilizing wearable technology and portable devices for monitoring vital signs, the system can collect physiological data in real time. This innovation facilitates seamless retrieval and review of electronic medical records via handheld devices and command centers. The approach also ensures a more thorough and uniform compilation of medical data and addresses the challenges associated with exchanging medical information across different regions [9]. Additionally, our system securely aggregates data from various healthcare providers, which supports the effective distribution of emergency medical resources. For instance, our system enables the systematized recommendation of transfer locations for urgent blood transfusions by analyzing the availability of blood products and orchestrates logistical planning for drones and vehicles to expedite the delivery of these products. In a city-based trial, implementing this system resulted in a reduction in the average patient wait time from 32 min to 18 min and in the overall response time from 42 min to 29 min [19].



(caption on next page)

Fig. 4. Comparison of the total survival rate and evacuation rate. (a) Same speed and number of ambulances, different number of patients. (b) The number of casualties is the same, but the speed and number of ambulances are different. (c) Comparison of evacuation efficiency with the same simulation runtime.

During mass gatherings, it is especially important to quickly collect, assess, and record patient information as they continually emerge in large numbers. In scenes characterized by dense populations and significant noise, medical professionals face an extensive workload. To enhance efficiency in the documentation of electronic medical records, our approach incorporates a combination of manual entry and a voice-activated application to optimize the use of doctors' hands. It must be acknowledged that the efficacy of voice recognition in high-decibel settings requires additional enhancement. Moreover, our system supports comprehensive visual management throughout the emergency medical service workflow. Christou et al. implemented mobile telemedicine devices to monitor patient conditions at the site of an incident, facilitating real-time transmission of vital signs [20]. By integrating these images into our platform, we can obtain a multidimensional perspective of medical data. This integration elevates the caliber of emergency medical services and affords commanders more robust oversight of emergency situations.

Presently, there are many operations research methods and domain search algorithms for optimizing the evacuation decisions of mass casualty events [21–26]. However, most of these methods consider only a single objective and consider patient injury to be static, which is not necessarily applicable to the long-term evacuation of mass gatherings. Such a setting is also related to the reliance on the existing emergency medical services system. Due to the inability to obtain real-time updates on patient conditions and the real-time availability of medical resources from different hospitals, it is necessary to establish such conditions when optimizing objectives. However, when we face the possibility of a mass casualty incident (MCI) during large public events, which relies on the medical resource information and comprehensive diagnostic information of patients obtained through our system, we can consider how to balance medical resources to enhance the overall quality of emergency medical services. In our simulation study, we considered the potential waiting time for patients upon arrival at the hospital, a period during which their condition may continue to deteriorate. This aspect, previously overlooked and deemed difficult to implement in prior research, has been addressed by our system and infers approximate waiting times based on the occupancy of medical resources, such as operating rooms, at the hospital. In particular, in scenarios 2 and 3, when the survival rates of our proposed method surpassed those of the other methods, the transportation speed was also the fastest. First, our algorithm considers that an ambulance can simultaneously transport two patients during an MCI, which may greatly enhance the efficiency of transport. Additionally, our algorithm selects hospitals for patients based on their condition upon arrival, with the optimization goal being the lightest overall condition upon reaching the hospital. This finding implies that patients

Table 3
Treatment capacity of the three hospitals.

	Patients RPM (<5)	Patients RPM (5–9)	Patients RPM (>9)
Second Affiliated Hospital of Zhejiang University Medical College	95 % patients stop deteriorating	100 % patients stop deteriorating	100 % patients stop deteriorating
Tongxiang First People's Hospital	85 % patients stop deteriorating	100 % patients stop deteriorating	100 % patients stop deteriorating
Wuzhen People's Hospital	60 % patients stop deteriorating	100 % patients stop deteriorating	100 % patients stop deteriorating

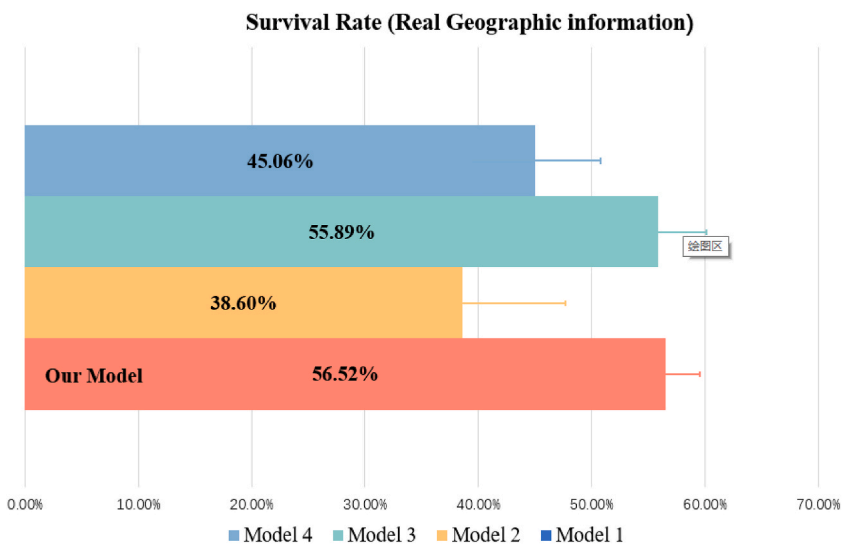


Fig. 5. Survival rate was compared with real geographic information.

require less time for treatment upon hospitalization, leading to increased turnover rates for emergency beds and operating rooms, which allows more patients to receive treatment concurrently. According to the results of scenario 5, although our algorithm improves the turnover rate in the hospital, in the case of the MCI, the transfer speed of the emergency vehicle is also critical, which requires the overall support of a system that can help the vehicle quickly arrive at the hospital, which is exactly what our system can realistically achieve.

4.2. Limitations

Within the context of short-duration mass gatherings, a range of practical challenges emerge, establishing an empirical basis for the future provision of an EMS at prolonged mass gatherings.

The implementation and operationalization of this novel system encounter significant hurdles. The system, which is characterized by extensive reliance on video surveillance and communication capabilities, demands robust network performance, with high speed and broad bandwidth connectivity. Notably, even with the current 4G and wireless infrastructures, there is appreciable latency. It is anticipated that advancements in 5G technology may ameliorate the issues associated with video signal delays.

The simplicity of conventional paper documentation remains advantageous in the domain of emergency medical services during major events. Operationally, our system design aligns with the prerequisites for comprehensive electronic medical records for patients. Nevertheless, future enhancements to the system will focus on seamless integration with the practical steps involved in real-world emergency response scenarios.

In our simulation studies, the spatial relationships between hospitals and incident sites were considered without fully incorporating mapping and traffic data. Future development efforts will be aimed at establishing a simulation framework that incorporates real-time mapping functionalities. Additionally, the simulations revealed a considerable discrepancy in patient distribution to hospitals, necessitating high-throughput capacity within the hospitals while concurrently diminishing their capacity to manage routine emergencies.

Recent emergency medical service studies have begun to give attention to the relationship between individual patients and overall medical efficiency, but the consideration of medical resources remains insufficient. Kyohong Shin and Taesik Lee suggested that patients should consider hospital status when choosing a hospital [27]. Therefore, we plan to consider the influence of currently available medical resources on the future operation of medical institutions.

5. Conclusion and future work

We have developed a comprehensive emergency medical information system for large-scale gatherings and a corresponding application to provide an all-encompassing approach to emergency medical services. This system addresses issues arising from insufficient acquisition and sharing of medical information across multiple institutions and sources. Furthermore, based on this system, we devised a transport method for potential mass casualty incidents (MCIs) that significantly enhances overall survival rates and the efficiency of patient transportation. This provides a systematic approach to improving the efficiency and quality of emergency medical services in the future.

In the context of the Hangzhou Asian Games, which have just concluded, the deployed system encompassed the surveillance of 54 venues and provided medical assistance to more than 11,000 individuals. Integration with the emergency medical services (EMS) in Hangzhou, which is designated the 120 first aid system, facilitated the dynamic consolidation of pertinent medical data from the Asian Games events, thereby enhancing the strategic allocation of first aid resources and the efficacy of the medical emergency response. After the culmination of the event, the commendation was received from the stadium support team at the Hangzhou Olympic Sports Center—a pivotal site for the games. The team highlighted the instrumental role of our system in enabling the instantaneous visualization and statistical evaluation of medical treatment data, which in augmented the overall operational efficiency, resource deployment, and strategic decision-making processes of the command center. The advanced data consolidation capabilities of our system lay the groundwork for improved medical resource planning for future events of comparable magnitude.

In future work, our focus will be to harness an assortment of data that our system can acquire without compromising safety to enhance the allocation and refinement of diverse urgent healthcare provisions. Furthermore, we plan to devise more sophisticated algorithms for the triage of patients who account for the overarching ramifications for healthcare resource distribution.

CRediT authorship contribution statement

Yu Tian: Writing – original draft, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Zhuyi Shen:** Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Yinghao Zhao:** Resources, Data curation. **Tianshu Zhou:** Data curation. **Qiang Li:** Data curation. **Mao Zhang:** Writing – review & editing. **Jingsong Li:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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