Review

MASS CASUALTY INCIDENTS AND HEALTHCARE SYSTEM CHALLENGES: CAPACITY ADAPTATION AND EMERGENCY MEDICAL COORDINATION

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Abstract: Mass casualty incidents (MCIs) place enormous strain on healthcare systems, demanding swift, well-organised medical responses. Events such as large-scale accidents, natural disasters, and pandemics result in a sudden influx of critically injured patients, necessitating a rapid increase in hospital capacity, effective triage, and seamless coordination among emergency services.

One of the key challenges is maintaining quality care while managing high patient numbers. This involves activating surge protocols, deploying mobile medical units, and transferring stable patients to free up intensive care resources. A reliable supply chain for essential equipment, ventilators, surgical tools, and blood products is crucial.

Efficient triage is vital for prioritising care and optimising resource use. Standardised triage systems, supported by artificial intelligence and wearable monitoring devices, enable quick assessment of patient severity and guide clinical decisions.

Effective emergency coordination relies on real-time communication among hospitals, responders, and public agencies. Digital platforms, electronic health records, and geographic information systems enhance situational awareness, data sharing, and resource distribution. Helicopter transport and evacuation protocols help balance hospital loads.

Technology plays a vital role in managing MCIS. AI-driven systems can forecast patient inflow and streamline logistics, while GIS tools assist in the targeted deployment of emergency teams.

Long-term resilience relies on routine simulation exercises, disaster preparedness training, and international collaboration. Unified protocols and cross-border resource sharing strengthen global readiness.

Proactive integration of medical, technological, and logistical strategies is crucial for effective MCI response. Enhancing triage systems, communication networks, and infrastructure will reduce the impact of future crises and improve patient outcomes.

Keywords: mass casualty incidents, crisis management, medical logistics, triage systems, healthcare system resilience

1. Introduction

Mass casualty incidents (MCIs) present a profound challenge to healthcare systems due to the sudden and overwhelming surge in individuals requiring urgent medical care. These events disrupt routine healthcare operations, as the number and severity of casualties often exceed the system's standard emergency and hospital capacity. MCIs may arise from large-scale traffic accidents, terrorist attacks, natural disasters (e.g., earthquakes, floods, wildfires), or public health crises such as the COVID-19 pandemic (Hugelius, Becker, & Adolfsson, 2020; Suda et al., 2025). Their unpredictable nature demands rapid recognition, swift response, and immediate mobilisation of all available resources.

The complexity of MCIs extends beyond the volume of patients—it involves the uneven distribution of casualties, variable injury severity, limited availability of critical medical equipment, and the need for real-time coordination with emergency services. Healthcare providers must triage and treat patients under uncertain conditions, often with incomplete information and in compromised environments (Dittmar et al., 2018). Logistical obstacles further complicate the situation. Transportation routes may be inaccessible, essential utilities such as electricity and water may be disrupted, and communication networks can become overloaded. In such settings, coordinated efforts across multiple sectors, including hospitals, ambulance services, fire departments, police, military, and crisis management teams, are essential (Homier et al., 2018). Health systems lacking adequate preparedness frequently experience breakdowns in the critical early hours, contributing to higher mortality and long-term morbidity.

To address these challenges, a range of tools and protocols have been developed over the past two decades. These include triage systems such as Simple Triage and Rapid Treatment (SALT) and Sort-Assess-Lifesaving Interventions-Treatment (SALT), digital vital signs monitoring, patient evacuation protocols, and resource allocation algorithms. However, research shows their implementation remains inconsistent, even in high-resource settings (Malik et al., 2021; Cross & Cicero, 2013).

Given these limitations, it is essential to identify which system components offer greater resilience, which adaptation strategies have been most effective, and how overall readiness can be enhanced. This paper focuses on two critical dimensions of MCI response: healthcare system

capacity and surge adaptation in the immediate aftermath of an incident. These factors are foundational, as without sufficient space, equipment, and coordinated protocols, clinical expertise and healthcare personnel cannot be fully leveraged to save lives.

2. Critical Medical Resources During MCIs

In MCIs, healthcare systems must rapidly expand capacity, not just by adding beds, but through comprehensive reorganisation. This includes spatial reallocation, staff redistribution, and securing critical care equipment such as ventilators and infusion pumps (Risavi et al., 2013). Surge capacity refers to all strategies that enable hospitals to function beyond their standard operations (Suda et al., 2025). The process begins with the activation of crisis protocols, shifting hospitals into emergency mode. Intensive care units may be set up in operating rooms, waiting areas, or hallways. Additional capacity can be provided via mobile hospitals, tents, and cooperation with civil protection or military forces (Amlot et al., 2017). Simultaneously, stable patients are discharged early to prioritise critical care.

During the COVID-19 pandemic, ventilator and staff shortages contributed to high mortality rates, prompting hospitals to repurpose anaesthesia machines and redeploy staff from other departments (WHO, 2022). Pre-developed, well-rehearsed plans are essential, as studies show that simulations and drills significantly improve preparedness (Andreatta et al., 2010; Mills et al., 2020). Effective plans should include logistics protocols, command hierarchies, staff and equipment inventories, and standardised crisis reporting methods. Robust vertical and horizontal communication is also crucial, including coordination between emergency services and hospitals, as well as among hospitals within the same network (Ophir et al., 2014). Real-time digital platforms that indicate available beds, ventilators, and institutional status enhance resource allocation (Homier et al., 2018).

A frequently overlooked consequence of prolonged mass-casualty events or pandemics is the indirect impact on patients with chronic illnesses. When healthcare systems remain in crisis mode for extended periods, resources, including specialists, diagnostic capacity, and hospital beds, are redirected almost exclusively to emergency care. During the COVID-19 pandemic, many countries reported delayed check-ups, postponed surgeries, and reduced access to outpatient

services, resulting in worsened control of chronic diseases and increased long-term morbidity. Therefore, preparedness planning must also include strategies to maintain essential chronic care services through telemedicine, decentralised medication delivery, or protected clinic zones, so that routine patient populations do not suffer avoidable harm (Cicurel et al., 2025; Ghanbari-Jahromi et al., 2024; Khoshmaram et al., 2025; Parotto et al., 2025).

Ultimately, effective surge adaptation requires years of planning, regular testing, and proactive investment. Without this, MCI responses risk becoming chaotic, leading to preventable mortality and prolonged crises. Effective surge adaptation is a cornerstone of MCI preparedness, as it enables healthcare systems to expand rapidly and maintain life-saving care despite overwhelming patient volumes.

3. Human Resources and System Resilience in MCIs

One of the greatest challenges during MCIs is the rapid depletion of essential medical resources. As hospitals quickly reach capacity, the demand for critical items such as ventilators, infusion pumps, surgical kits, blood products, oxygen, antibiotics, analgesics, and vasopressors rises exponentially (Suda et al., 2025; Frykberg, 2002). Shortages often occur within hours of the event, significantly impairing the treatment of severely injured patients.

Personal protective equipment (PPE) is another urgent necessity, especially during chemical, biological, or infectious outbreaks. The COVID-19 pandemic starkly illustrated this, with hospitals in Europe and the U.S. reporting dangerous PPE shortages that led to compromised care and increased mortality among healthcare workers (Amlot et al., 2017; Chilcott et al., 2019; WHO, 2022). Efforts to mitigate shortages, such as local manufacturing, military support, and alternative supply chains, were often inconsistent and delayed (Larner et al., 2020).

In addition to hospital personnel, primary care physicians play an important but often underestimated role during MCIs (Bamgboje-Ayodele et al., 2024). General practitioners (GPs) are frequently the first medical contact for the community, yet many primarily office-based physicians lack training in prehospital triage or emergency medicine. During large-scale incidents, GPs may need to be rapidly mobilised to support hospital teams, work in mobile medical units, or staff temporary care points. Targeted education in triage, basic trauma management, and

emergency communication protocols would significantly increase system flexibility (Suda et al., 2025; Ugelvik et al., 2025). Evidence from recent crises shows that healthcare systems which integrated primary care workers into emergency pathways demonstrated faster patient flow, better continuity of care, and reduced burden on hospital emergency departments (Alesi et al., 2023; Bamgboje-Ayodele et al., 2024).

To prevent critical gaps, many hospitals are adopting predictive models and real-time inventory tracking systems. These tools integrate data on stock levels, patient volume, and projected needs, enabling rapid redistribution within hospital networks (Paul et al., 2009; Jat & Rafique, 2020; OCEBM, 2009). While such systems are standard in military settings, their use is expanding in civilian healthcare. Digital dashboards and electronic inventory management may improve visibility and coordination, particularly in integrated networks (Collins et al., 2021).

When infrastructure is damaged and supply lines disrupted, predictive monitoring becomes essential. Resource management often shifts from hospital administrators to dedicated logistics teams, who oversee emergency deliveries, identify alternative suppliers, and make real-time allocation decisions. Some European countries have developed mobile logistics units capable of deploying within hours to deliver supplies directly to affected sites (Stratmann, 2003; Bubser et al., 2014; Hao et al., 2024; Xia et al., 2023).

To strengthen preparedness, experts recommend that hospitals maintain tactical reserves such as emergency stockpiles of critical supplies, including medications, infusion solutions, respirators and emergency procedures kits sufficient for at least 72 hours of autonomous operation (Deutsche Gesellschaft für Unfallchirurgie, 2016; AWMF, 2020). These reserves can be life-saving when standard supply chains fail.

Resource management during MCIs extends beyond supplies; staffing is often the greater challenge. Medical personnel face fatigue, stress, overlapping shifts, and psychological strain. To address this, some countries have implemented protocols for staff rotation and mental health support during crises (Knight et al., 2010; Andreatta et al., 2010). A growing trend is the creation of pre-established registries of trained medical professionals at regional or national levels, allowing rapid deployment without relying on ad hoc volunteer systems (Achatz et al., 2020).

Major disasters such as the Italy earthquake, the Beirut explosion, and the COVID-19 pandemic have demonstrated that decentralised healthcare systems are more resilient. Distributing patients and resources across multiple institutions helps prevent the overload and collapse of individual facilities (Cheng et al., 2020). “Peer-support” or “sister-hospital” models, where institutions are paired for mutual support during crises, are increasingly adopted across European networks. These partnerships ease logistics and provide emotional reassurance for staff, knowing help is structured and available (Shimonovich et al., 2016).

Ultimately, timely and coordinated management of human and material resources is essential to preserving system functionality and delivering life-saving care when it is needed most.

4. Triage and Prioritisation

In the chaotic first minutes of an MCI, hospitals and emergency teams face uncertainty about patient numbers, conditions, and resource needs. Triage becomes critical to prevent system overload, ensure the fair distribution of care, and avoid both under- and overtreatment (Benson et al., 1996; Frykberg, 2002; Suda et al., 2025).

Standardised systems like START and SALT were developed to guide field personnel in rapid decision-making based on breathing, pulse, and consciousness, without relying solely on intuition or diagnostics (Cross et al., 2015). These tools help match care to available resources in real time. However, their effectiveness can be limited. Vulnerable populations such as children, the elderly, and people with disabilities may present atypical symptoms or respond differently to treatment, making standard triage less accurate for these groups (Muguruma et al., 2019; Cicero et al., 2021). Despite limitations, structured triage remains essential for managing patient flow and optimising outcomes in mass casualty situations.

To enhance emergency response, new triage tools have been developed, incorporating real-world trauma data and clinical experience. The Battlefield Casualty Drill (BCD) Triage Sieve offers greater accuracy in predicting treatment needs compared to traditional systems (Malik et al., 2021). Tools like the National Early Warning Score **(**NEWS2), though originally designed for inpatient monitoring, are now adapted for rapid risk assessment in emergencies (Martin-Rodriguez et al., 2019).

Emerging technologies may also aid triage. Artificial intelligence (AI)-powered smartphone apps can assess bleeding, fractures, and consciousness using a camera, supporting but not replacing clinical judgment (Knight et al., 2010). Wearable sensors that track vital signs, including oxygen saturation and heart rate, may assist during patient transport or prolonged waiting before further examination (Cheng et al., 2020).

Electronic triage tags have replaced paper wristbands, storing patient data, triage category, and destination. This data, when uploaded to a central system, improves coordination and reduces errors (Paul et al., 2009; Collins et al., 2021). Nevertheless, the most demanding aspect remains the decision-making itself. Choosing who receives limited resources, such as the last intensive care unit (ICU) bed, under pressure and uncertainty, often leads to emotional distress among staff (Wilkinson et al., 2020).

Triage skills deteriorate quickly without practice. Studies show confidence and accuracy drop within a year if not reinforced (Dittmar et al., 2016). Low-cost training methods, including virtual reality (VR) simulations, serious games, and live drills, have proven effective in building lasting competence (Cicero et al., 2017; Mills et al., 2020; Cuttance et al., 2017). Regular, practical training and updated triage protocols are essential to delivering fast, ethical, and resource-conscious care during MCIs.

5. Coordination and Communication

Effective communication is the backbone of the MCI response. Without timely and accurate information, care is delayed, resources are misallocated, and lives are lost, not due to a lack of skill, but rather a lack of situational awareness (Homier et al., 2018). Hospitals may not be informed about incoming patients, dispatchers lack up-to-date information on capacity, and emergency teams operate without insight into available beds and staff resources.

Timely and accurate knowledge of resource availability is essential for effective patient redirection. In its absence, hospitals risk becoming overwhelmed in an uncoordinated manner, resulting in a cascading system overload that cannot be promptly mitigated. (Cheng et al., 2020; WHO, 2022). Digital dashboards displaying bed and equipment status across hospital networks can be helpful if they are consistently updated and shared with all stakeholders, including dispatchers (Collins et al., 2021).

Overloaded hospitals that continue to receive patients become critical bottlenecks. Clear diversion protocols based on priority, proximity, and capacity can prevent a cascade of failures throughout the system (Paul et al., 2009). In rapidly evolving disasters, such as earthquakes or chemical incidents, geographic information systems (GIS) play a crucial role in managing routes, vehicle tracking, and transport logistics, especially when roads are blocked or resources are limited (Stratmann, 2003; Zhang et al., 2025).

Air transport is only effective if ICU beds and safe landing zones are confirmed in advance. Without this, even the fastest response can fail (Vassallo et al., 2015). Predefined communication protocols, more than just contact lists, specify who reports what, when, and to whom. Mass notification systems and even apps like WhatsApp have proven more efficient than traditional call chains in mobilising staff (Homier et al., 2018). Robust and integrated communication systems are vital for coordinating healthcare delivery, mitigating system overload, and ensuring that timely and appropriate care is provided to those in greatest need.

Effective communication protocols extend beyond mere contact directories; they establish clear guidelines on the content, timing, and recipients of critical information. When integrated into emergency response plans, mass notification systems, including platforms such as WhatsApp, have

demonstrated greater efficiency in mobilising personnel compared to conventional phone trees (Homier et al., 2018).

While it's impossible to predict who will be present during an MCI, decision-making roles must be assigned in advance—whether to a dispatcher, emergency manager, or hospital administrator. Shared responsibility leads to confusion. Coordination improves when hospitals operate within a common system and understand each other's capacities. This is supported not only by technology but by trust and established relationships. Some regions use hospital pairing systems, ensuring backup capacity when one facility becomes overwhelmed (Deutsche Gesellschaft für Unfallchirurgie, 2016).

In the event of digital system failures, whether caused by power outages, network disruptions, or technical malfunctions, reliable backup communication methods become indispensable. These may include two-way radios, designated couriers, or mobile relay teams. Establishing robust and well-defined communication frameworks is crucial for transforming disjointed efforts into coordinated, life-saving responses during MCIs.

6. Training and Long-Term Preparedness

Improvisation is insufficient when the healthcare system is overwhelmed. Frontline personnel must know precisely what actions to take, whom to contact, and how to operate when standard protocols break down. This requires a clear, well-structured plan supported by prior experience, ideally gained through simulations, drills, or training exercises. While mass casualty events are rare, their unpredictability can quickly undermine assumptions. Preparation must go beyond theoretical knowledge and be tested under realistic, high-stress conditions (Andreatta et al., 2010; Mills et al., 2020).

Field exercises involving emergency services, hospitals, and local authorities enhance interagency coordination and assess not only clinical performance but also communication flow, command efficiency, and adaptability to unexpected challenges such as power failures, false alarms, or sudden patient influxes. Individuals with prior simulation experience are significantly better prepared to respond effectively during real crises (Dittmar et al., 2018; Cuttance et al., 2017).

Beyond initial drills, continuous training is essential. Triage protocols, trauma care, and crisis communication evolve, and without regular refreshers, response capabilities deteriorate.

Evidence shows that proficiency in mass casualty response significantly declines within 1 year of initial training (Dittmar et al., 2016; Schulz et al., 2024). To maintain readiness, many institutions implement brief mandatory workshops or digital simulations multiple times each year (Schulz et al., 2024).

Preparedness must also extend beyond hospital settings. Public knowledge of basic first aid, evacuation procedures, and emergency response can significantly alleviate the burden on professional services during major incidents. Immediate responders are often bystanders, and empowering them to act, such as stopping bleeding or safely extracting victims, can save lives (Amlot et al., 2017).

Given the cross-border nature of many incidents, especially at airports, border zones, and international transit routes, global coordination is essential. Countries are increasingly adopting joint response protocols, sharing critical equipment, and deploying reserve medical teams across borders when necessary (Deutsche Gesellschaft für Unfallchirurgie, 2016; Achatz et al., 2020). Regional agreements that recognise each other's training and certifications help eliminate bureaucratic obstacles and enable faster, more effective personnel deployment (Knight et al., 2010).

At the national level, clear governance is crucial. A well-defined protocol that designates who can declare a mass casualty event and outlines the chain of command is essential to the swift and coordinated activation of the system. Preparedness must be practical, not just theoretical. Protocols and equipment are only effective if they are familiar, readily accessible, and regularly tested through real-world exercises (Abbas & Miller, 2025; Steen-Tveit et al., 2024).

Effective systems do not ask whether every scenario was predicted, but whether people were equipped to act when the unexpected occurred. Sustained investment in training, simulation, and cross-sector coordination directly enhances the speed, safety, and efficiency of real-world responses. Table 1 summarises the critical components of an effective healthcare response to mass casualty incidents, emphasising their strategic roles in managing large-scale emergencies.

Table 1. Strategic Components of Healthcare System Response to Mass Casualty Incidents

Response Component	Key Functions and Tools	Strategic Role in MCI Management
Surge Capacity	• Rapid expansion of treatment areas • Conversion of non-clinical spaces • Activation of emergency protocols • Mobile medical units and temporary structures	• Enables rapid scaling of clinical infrastructure • Optimises space for critically injured patients
Medical Resource Management	• Real-time inventory tracking • Predictive supply chain models • Emergency logistics teams • Mobile supply units • 72-hour tactical stockpiles	• Ensures uninterrupted access to essential medical supplies • Reduces treatment delays during high demand
Triage Systems	• Standardised triage tools (START, SALT, BCD) • AI-based decision support • Wearable vital sign monitors • Electronic triage tags integrated with digital systems	• Improves patient prioritisation • Facilitates efficient allocation of limited resources
Coordination and Communication	• Integrated digital dashboards and GIS mapping • Unified command structure and reporting protocols • Backup communication systems (e.g., radio, mobile relays)	• Enhances situational awareness • Minimises redundancy • Supports real-time decision-making across agencies
Training and Preparedness	• Simulation-based exercises and live drills • Multidisciplinary team training • Public education campaigns • Bilateral and regional response agreements	• Strengthens systemic readiness • Fosters interagency collaboration • Ensures continuity of care during crises

START: Simple Triage and Rapid Treatment; SALT: Sort–Assess–Lifesaving Interventions–Treatment; BCD: Battlefield Casualty Drills; AI: artificial intelligence; GIS: geographic information systems

6.1 Economic Challenges and Sustainable Financing in MCI Response

MCIs impose significant economic pressures on healthcare systems. The timely acquisition of essential resources such as ventilators, PPE, and mobile field units, along with expenses for overtime compensation and enhanced logistics, can significantly escalate hospital operational costs.

Research indicates that surge periods during MCIs raise both the length of hospital stays and overall charges for all patients, with average additional costs exceeding USD 20,000 per patient (Abir et al., 2012). Furthermore, preparedness activities such as large-scale hospital drills often carry substantial financial burdens, ranging from €10,000 to €100,000 per exercise (Schweigkofler et al., 2019).

To address these financial challenges sustainably, the following strategies are recommended:

1. Create dedicated emergency response funds at the national or regional levels to support rapid surge capacity.
2. Develop public-private partnerships with manufacturers to enable the swift scaling of emergency production.
3. Invest in multipurpose infrastructure that meets routine demands but can be quickly adapted for crises.
4. Use economic forecasting and disaster budgeting tools to optimise resource allocation.
5. Pre-negotiate supplier contracts and maintain rotating stockpiles to minimise acquisition delays and reduce waste.
6. Engage in international pooled procurement and shared logistics networks to lower unit costs, especially benefiting resource-limited regions.

Implementing these strategies ensures that the healthcare system remains financially resilient when responding to MCIs, enabling swift mobilisation without compromising everyday services.

7. Conclusion

Mass disasters allow no room for hesitation or mid-crisis corrections. When a system falters under pressure, it becomes a liability rather than a solution. Experience shows that the effectiveness of a response depends less on the scale of disasters and more on the level of preparedness

beforehand. Hospitals and emergency services that regularly practice triage, maintain up-to-date equipment inventories, establish clear chains of command, and ensure open communication stabilise situations more rapidly.

Investing in predictive tools, digital mapping, and automated resource allocation helps prevent delays and mistakes in patient transport. Regular drills and training in stressful situations build safety and confidence. True resilience comes from avoiding improvisation and relying on proven protocols and trusted contacts that can handle crises without breaking down.

This paper emphasises that preparedness is concrete and practical, reflected in staff's clear knowledge of equipment locations, defined decision-making authority, established communication roles, and streamlined patient transfer procedures. Without effective internal communication, a system cannot provide reliable support beyond its walls.

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MASOVNE NESREĆE I IZAZOVI ZDRAVSTVENOG SUSTAVA: PRILAGODBA KAPACITETA I KOORDINACIJA HITNE MEDICINSKE SLUŽBE

Sažetak:

Masovne nesreće (mass casualty incidents – MCI) predstavljaju značajno opterećenje za zdravstvene sustave te zahtijevaju brzu, dobro organiziranu i koordiniranu medicinsku reakciju. Događaji poput velikih prometnih nesreća, prirodnih katastrofa ili pandemija dovode do naglog priljeva teško ozlijeđenih pacijenata, čime se premašuju uobičajeni kapaciteti bolnica i hitnih službi. Održavanje kvalitete zdravstvene skrbi u tim okolnostima zahtijeva aktivaciju kriznih protokola, proširenje bolničkih kapaciteta, mobilizaciju mobilnih medicinskih jedinica te preraspodjelu postojećih resursa. Učinkovita trijaža, utemeljena na standardiziranim sustavima, ključna je za racionalno korištenje dostupnih resursa i donošenje prioritetnih kliničkih odluka.

Digitalne platforme, elektronički zdravstveni kartoni i geoinformacijski sustavi omogućuju bolju koordinaciju i uspješniju suradnju među bolnicama, hitnim službama i javnim institucijama. Tehnologija, uključujući alate temeljene na umjetnoj inteligenciji i prijenosni uređaji za nadzor vitalnih funkcija, dodatno unaprjeđuje učinkovitost odgovora zdravstvenog sustava. Dugoročna otpornost zdravstvenih sustava temelji se na redovitim simulacijama, sustavnoj edukaciji i međunarodnoj suradnji. Sustavi koji ulažu u preventivnu pripremu, jasno definirane protokole i međuinstitucionalnu komunikaciju znatno su učinkovitiji u upravljanju krizama te postižu bolje ishode za pacijente. Ovaj rad naglašava potrebu za integriranim pristupom koji povezuje medicinske, tehnološke i logističke resurse i strategije u svrhu jačanja spremnosti i kapaciteta zdravstvenih sustava u kriznim situacijama.

Ključne riječi: masovne nesreće, krizno upravljanje, medicinska logistika, trijažni sustavi, otpornost zdravstvenog sustava