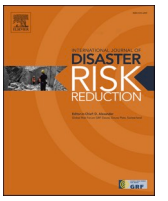
International Journal of Disaster Risk Reduction 102 (2024) 104281

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr



# Towards optimal decision making in mass casualty incidents management through ICT: A systematic review

Primož Režek [a], Boštjan Žvanut [b,*]

[a] University of Primorska, Faculty of Health Sciences, Polje 42, 6310, Izola, Slovenia, Osnovno zdravstvo Gorenjske, Zdravstveni dom Škofja Loka, 4220, Škofja Loka, Slovenia
[b] University of Primorska, Faculty of Health Sciences, Polje 42, 6310, Izola, Slovenia

ARTICLE INFO

*Keywords:*
Mass casualty incident
Decision support
Information and communication technology
Systematic review

ABSTRACT

*Objective:* To examine the prevalence and trend of experimental research on the effectiveness of ICT use in supporting the management of mass casualty incidents.
*Methods:* A systematic review was conducted in five electronic databases between February and March 2022 following the PRISMA guidelines. The analysis included studies published since 2012.
*Results:* A total of fifteen studies were included in the final analysis. Three themes were identified: 1) the response of medical teams to mass casualty incidents, 2) the simulation of mass casualty incidents, and 3) the digitisation of mass casualty incident workflows.
*Conclusion:* The available evidence is limited due to the relatively small number of studies on the use of information and communication technology and the response of emergency rescue teams to mass casualty incidents. Therefore, further research is needed on the impact of information and communication technology on the efficiency, work, and decision-making of incident commanders during mass casualty incidents. Furthermore, more dynamism is needed to accumulate knowledge and methodological expertise to explore experimental ideas in the European Union, where such research is lacking.

## 1. Introduction

To ensure that Emergency Medical Teams (EMTs) are always prepared for Mass Casualty Incidents (MCIs), it is crucial to anticipate and plan for such situations, even though they may be rare. Although there have been several attempts to define an MCI quantitively, the best definition is that the number of casualties exceeds the resources generally available at the scene [1]. In this article, we refer to MCIs not caused by terrorist attacks. The rationale for excluding them is rooted in the significant differences in managing such MCIs, which stem from the deliberate intention behind these events and the often disproportionate number of casualties they cause [2–8]. Between 1982 and 2012, 290 mass casualty incidents (MCIs) were analysed in the study conducted by Turris, Lund, and Bowles [9]. Out of these MCIs, 71 (24 %) occurred in Asia, 69 (24 %) in Europe, 48 (17 %) in Africa, 48 (27 %) in North America, 27 (9 %) in South America, 25 (9 %) in the Middle East, and 2 (1 %) in Australasia. In Slovenia, an MCI occurs on average once a year [10].

Efficient and rapid deployment of rescue services is critical. In such circumstances, the approach and execution of rescue service operations are very specific. Through the proper use of available resources, every effort must be made to save the lives and health of as many people as possible. Such an event regularly exceeds the depleted capacities of local services and the nearest hospitals. It requires

* Corresponding author.
*E-mail addresses:* primoz.rezek@gmail.com (P. Režek), bostjan.zvanut@fvz.upr.si (B. Žvanut).

https://doi.org/10.1016/j.ijdrr.2024.104281
Received 27 January 2023; Received in revised form 28 November 2023; Accepted 15 January 2024
Available online 23 January 2024

**Table 1**
The number of identified articles in each database.

| Pos. | Search term | PubMed | ProQuest | Scopus | Science Direct | Web of Science |
|---|---|---|---|---|---|---|
| | | (n) | (n) | (n) | (n) | (n) |
| 1 | "Crisis response" OR"Disaster medicine" OR "Disaster Planning" OR "Mass casualty incident" OR "Major incident" | 7 | 14 | 20 | 7,158 | 2754 |
| 2 | "triage" OR "case management" OR"decision support" | 46 | 120 | 22 | 178 | 106,922 |
| 3 | "Artificial intelligence" OR "AI" OR "software" OR "Technology" | 1,523,785 | 2,946,051 | 505 | 5,000,000+ | 6,972,424 |
| 4 | "Ethics" OR "Opportunities" OR"Risk" | 1,747,252 | 2,312,348 | 189 | 391 | 4,040,879 |
| 5 | NOT "terroris*" | 265 | 919 | 165 | 2,045,278 | 1,976,165 |
| **6** | **Combination (1 + 2+3 + 4+5)** | **10** | **97** | **85** | **31** | **13** |

rapid reorganisation of work and support from additional rescue teams and other hospitals. The main goal of the disaster response organisation is to fulfil the necessary tasks and reduce the number of fatalities in the first hours after a disaster. To manage MCIs safely and effectively, EMTs need the appropriate knowledge and skills. The prehospital phase of an MCI is typically chaotic, dynamic and evolving in nature**,** requiring prehospital management decisions to be made under extreme time pressure. In an MCI, evacuating severely injured patients to an appropriate medical facility is critical.

Although ICT is widely used in healthcare, its actual use in MCI management support has yet to be sufficiently explored and, therefore, remains unclear. Some examples of ICT use in MCI in the literature exist [11,12]. However, its effectiveness is mainly based on expert opinions rather than empirical research. Expert opinions may have several limitations. They are mainly based on experts' actual knowledge and experience with the ICT or ICT model tested, not necessarily on ICT's appropriateness, usefulness, or effectiveness concerning intervention management outcomes [13]. This represents a significant gap in ICT use in MCI.

ICT has the potential to enhance the management of MCI. They may offer a range of benefits by providing real-time data, facilitating communication and coordination, supporting decision-making processes, identifying system vulnerabilities, and enabling post-incident reviews to identify opportunities for improvement in ICT, thus improving both the efficiency and effectiveness of MCI management.

The effective integration of wireless solutions and ICT can be crucial in improving MCI management [14]. Integrating clinical data with other organisations' data promotes better collaboration and coordination among response agencies. In addition, mobile ICT provides timely alerts to relevant personnel, ensuring prompt initiation of response efforts. ICT enables effective two-way communication during relief activities, allowing seamless coordination between on-site responders, remote experts, and support personnel.

Different tasks that can be facilitated or improved with the support of ICT:

-*Triage* support*:* ICT can be beneficial in providing real-time data on the patient's condition and available medical resources. Triage systems typically utilise tags or colour-coded designations to identify areas of the injured for treatment and ambulance loading. Effective triage at such incidents requires prior training to ensure proficiency in this dynamic process [15–17].

- *Coordination:* ICT can help coordinate the efforts of different emergency response teams and agencies involved in the incident. This can include sharing real-time information on the location of victims, the availability of resources, and the status of ongoing operations. ICT can also assist in moving patients to designated areas based on the level of care and help gather patient information in the emergency treatment area [17,18].
- *Communication:* Effective communication is crucial in managing MCI. ICT can facilitate effective two-way communication during relief activities, allowing for efficient communication between emergency response teams, healthcare providers, hospitals, and other agencies.
- *Command and control:* ICT can help establish a command center to manage the MCI, including communication with different teams and agencies, resource allocation, and decision-making. Emergency Medical Services (EMS) agencies have sought guidance on better integrating their emergency preparedness and response activities into similar local, regional, state, and federal processes [19]. The primary purpose of the review is to begin providing guidance related to ICT use in MCI management.
- *Prioritisation of resources:* During an MCI, medical personnel, equipment, and supplies can quickly become overwhelmed. ICT can help prioritise allocating these resources based on the severity of injuries and the likelihood of survival. Evidence-based triage systems have been developed using documented triage basics and triage prioritises identifying those needing immediate intervention [17,18].

Based on the search results, a specific timeline of ICT development in crisis management of MCI could not be found. A scientometric analysis evaluated the ICT-assisted disaster management research in 15 years (2005–2020) [20]. The analysis revealed a growth in the number of publications on ICT-assisted disaster management over the years, indicating the increasing interest in this field of research. International collaboration among researchers was observed, indicating a global effort in addressing MCI management using ICT. This collaboration can lead to more effective solutions and knowledge sharing.

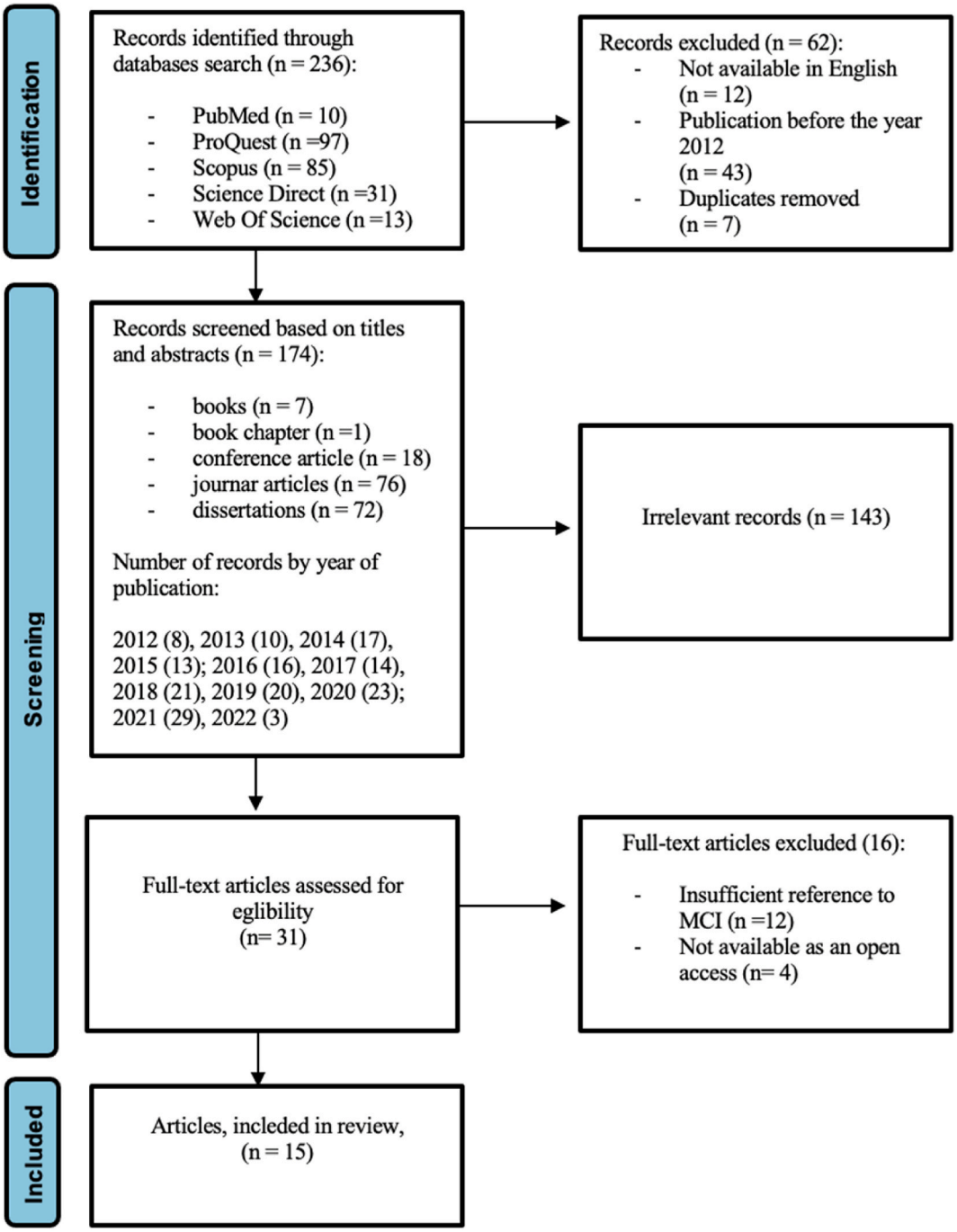



**Fig. 1.** PRISMA flow diagram.

In the realm of crisis management for MCIs, potential future developments in ICT include the use of advanced technology to improve response efficiency, the introduction of mobile emergency care units and remote technologies for disaster medicine education [21], the adoption of emerging information technologies like Internet of Things (IoT), Big Data, social media, and machine learning to enhance disaster visualisation, analysis, and prediction, the integration of diverse ICT systems to support coordination among professionals [21], the utilisation of drones [22] and smart surveillance technology for surveying and response, ongoing ICT evolution with real-time communication capabilities [23].

This systematic review aims to examine the prevalence and trend of experimental research on the effectiveness of ICT in supporting MCI management. This review focuses mainly on studies that can serve as a valid and reliable reference for identifying the impact of ICT support in MCI management. Accordingly, the following research question has been posed: Can the use of ICT in MCI protocols

**Table 2**
List of studies with relevant details.

| Authors | Title | Type | Country | MCI topic | Sim. MCI | Dig. | Details of ICT used | Impact of ICT on MCIs Service | Final Findings/Conclusions on ICT Impact on MCIs |
|---|---|---|---|---|---|---|---|---|---|
| (Reay, Rankand, Dobson, Campbell, 2022) | Mass casualty triage for the Emergency Department using the RATE protocol: Validation and results of a quasi-experiment | Journal Article | Canada | Yes | No | Yes | The study validates the RATE protocol and compares infographic vs. e-learning for training triage of Registred Nurses. | The RATE infographic and e-learning module were both effective in training RNs on the RATE protocol, with no significant performance difference. Either method can be used for training. | Both the RATE infographic and e-learning module effectively trained RNs on the RATE protocol with no significant difference in performance. Either method can be used for training, with infographic preferred in resource-poor environments or for just-in-time training. |
| (Alvarez-Garcia et al., 2021) | Development of the Aerial Remote Triage System using drones in mass casualty scenarios: A survey of international experts | Journal Article | Spain | Yes | No | Yes | Explores how drones with cameras and sensors can enhance response efforts and real-time communication with bystanders during MCIs. | The use of drones with ICT can improve response speed and effectiveness, though challenges and skepticism exist. It provides a framework for remote triage using drones. | Drones with cameras, sensors, and remote communication technology can improve emergency response in MCIs. Careful planning is necessary to address challenges in using ICT in MCIs. The study provides a framework for testing a remote triage procedure using drones, which could save lives in MCIs. |
| (Tresenriter, Holdaway, Killeen, Chan, and Dameff, 2021) | The implementation of an emergency medicne telehealth system during a pandemic | Journal Article | USA | No | No | Yes | Discusses using ICT, including real-time audio-video and health record messaging, for emergency telehealth. | Focuses on the implementation of ICT in telehealth during a pandemic, mainly for communication and remote patient evaluation. | The paper does not provide specific findings or conclusions on the impact of Information and Communication Technology (ICT) on MCIs. |
| (Redford, 2021) | Perceptions of the use of augmented and virtual realty supporting emergency response education and training | Dissertation | USA | Yes | Yes | Yes | Examines VR/AR tech in emergency response training and education, and the benefits of ICT for responders. | VR/AR technology simulations can improve training, address barriers, and provide a more engaging learning experience. | Emergency responders can learn complex skills like situational awareness, decision-making, communication, teamwork, and leadership through simulations. VR/AR technology can provide a more immersive training experience, leading to increased skill acquisition and knowledge retention compared to traditional training methods. |
| (Sheikh et al., 2021) | Toward an Integrated Disaster Management Approach: How Artificial Intelligence Can Boost Disaster Management | Journal Article | Malaysia, Canada, Korea, Spain | Yes | Yes | Yes | Discusses the potential of ICT, specifically AI and machine learning, in improving disaster preparedness, response, and recovery efforts. Integration of ICT enhances response efficiency. | The use of AI, machine learning, and GIS in disaster management improves data analysis, communication, and decision-making. ICT integration enhances disaster management. | ICT, AI, and GIS can improve disaster management with precise information. Digital tech and social media enhance communication. Geographical implications must be considered. More research needed. |
| (Greco, Lewis, Sanford, Sawand, and Ames, 2019) | Ethical Reasoning Debriefing in Disaster Simulations | Journal Article | USA | Yes | Yes | Yes | References high-fidelity simulators, standardised patients, and the use of triage tags in disaster simulations. Discusses the importance of ICT tools and | While not directly focused on ICT's impact on mass incidents, the paper discusses how ICT tools can support the Simple Triage and Rapid Treatment | ICT tools are useful in disaster nursing and emergency preparedness, but not enough. Successful disaster response requires strong relationships, effective communication, and |

(*continued on next page*)

**Table 2** (*continued*)

| Authors | Title | Type | Country | MCI topic | Sim. MCI | Dig. | Details of ICT used | Impact of ICT on MCIs Service | Final Findings/Conclusions on ICT Impact on MCIs |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | applications in disaster nursing and preparedness. | (START) system in disaster management. | well-trained healthcare professionals, supported by appropriate ICT tools. |
| (Kondo et al., 2019) | Current Disaster Medicine in Japan and | Journal Article | Japan | Yes | Yes | Yes | Highlights the role of ICT in disaster medicine, particularly the Sharing Information Platform for Disaster Management (SIP4D). Discusses the incorporation of AI and electronic medical records in disaster medicine. | The use of SIP4D improves Disaster Medical Assistance Team (DMAT) operations. ICT enhances medical operations, communication, and data analysis in disaster response. | ICT has improved disaster medicine in Japan by sharing information via SIP4D, using electronic medical records, cloud systems, and AI. However, more improvements are needed in estimating disaster severity, calculating resources, and setting regulations. |
| (Bertrand, Lecarpentier, Herodand, and Dorandeu, 2019) | Triage Issues in a CBRNE Crisis: Experiences from European projects | Book Section | Switzerland | Yes | No | No | No particular ICT is described | The impact of ICT on MCIs is a complex issue that needs further research and study, emphasizing potential benefits and challenges. | ICT has improved emergency response time, communication, and resource management during MCIs. However, technical problems and data privacy concerns need to be addressed. Further research is needed to fully understand the impact of ICT on MCIs. |
| (Praiwattana, 2018) | Investigation into game-based crisis scenario modelling and simulation system | Dissertation | UK | Yes | No | Yes | Discusses the use of game-based simulations for crisis management training and its benefits, such as cost-effective training, multidisciplinary integration, and practical basis for emergency situations. | Highlights the cost-effective and practical nature of game-based simulations for training crisis management personnel. | The paper explores the use of game-based simulations for training crisis management personnel. It discusses the challenges of involving domain experts and acquiring input data. It concludes that game-based simulations are a practical and cost-effective training solution. |
| (Eaglin, 2017) | Scalable, situationally aware visual analytics and applications | Dissertation | USA | No | Yes | Yes | Discusses the use of ICT in various aspects of research, including mobile devices, social media data analysis, and situational awareness in critical environments. | Emphasizes the potential uses of ICT in emergency response, including mobile devices and social media data analysis. | The paper does not provide specific findings or conclusions on the impact of ICT on Mass Casualty Incidents (MCIs). |
| (Robinson, 2017) | Sustaining Innovations and Disruptive | Dissertation | USA | No | No | Yes | Discusses the role of ICT in enabling disruptive innovation in healthcare delivery, focusing on mobile communication technology and dynamic evaluation of smartphone applications. | Highlights the potential for disruptive innovation in healthcare delivery through ICT, particularly mobile communication technology. | The paper does not provide specific findings or conclusions on the impact of ICT on Mass Casualty Incidents (MCIs). |
| (Price et al., 2016) | Performance characteristics of five triage tools for major incidents involving traumatic injuries to children | Journal Article | UK | No | Yes | No | No particular ICT is described | The paper does not discuss the impact of ICT on MCI service and focuses solely on the performance characteristics of triage tools for traumatic injuries in children. | The paper does not provide specific findings or conclusions on the impact of ICT on Mass Casualty Incidents (MCIs). |

(*continued on next page*)

**Table 2** (*continued*)

| Authors | Title | Type | Country | MCI topic | Sim. MCI | Dig. | Details of ICT used | Impact of ICT on MCIs Service | Final Findings/Conclusions on ICT Impact on MCIs |
|---|---|---|---|---|---|---|---|---|---|
| (Nikolai, 2015) | SIMEOC: a virtual emergency operations center (VEOC) simulator for training and research | Dissertation | USA | No | Yes | Yes | Describes the use of ICT, such as Java programming, virtual machines, and SSL, in the development of a virtual emergency operations center simulator. | The focus is on the development of a virtual emergency operations center simulator using ICT for training and research, rather than the direct impact of ICT on MCIs. | The paper does not discuss the impact of Information and Communication Technology on MCIs. |
| (Hashemipour, 2017) | A Multi-Agent Simulation System to Evaluate the Disaster Response Team Coordination and Performance | Dissertation | USA | No | Yes | Yes | Acknowledges the role of ICT in improving disaster response operations, particularly in facilitating communication and coordination among disaster response teams. | Recognizes the importance of ICT in disaster response and proposes a novel approach to evaluating disaster response teams using a multi-agent simulation system. | The paper doesn't discuss ICT's impact on MCIs. It focuses on creating a virtual emergency operations center simulator for training and research. The conclusion highlights the simulator's effectiveness as a tool for emergency managers. |

Legend: Sim. MCI – Simulation MCI, Dig. - digitsation

provide better results than pen-and-paper approaches?

## 2. Methods

The systematic review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [24].

## 3. Protocol and registration

A review protocol was developed, which included information on the search conditions, databases and screening criteria to guide the literature search. A free version of Covidence [25] software was used to reduce the time required for the review. By following the PRISMA guidelines, we reduced bias from subsequent changes and adjustments in the review process. Thus, we determined the objectives and methods of the review in advance and consistently defined the inclusion and exclusion criteria.

The objectives, eligibility criteria, sources of information, study selection process, and data collection procedures and uses were defined in advance. Changes to search terms due to search restrictions with a maximum of eight Boolean operators were documented separately in the ScienceDirect database.

### 3.1. Eligibility criteria

Limited research has been conducted on utilising ICT to assist EMTs during MCI. To address this gap, we reviewed studies published since 2012, as the number of studies in the last three years is notably scarce.

We conducted a systematic review to identify relevant records through multiple databases and selected them based on specific inclusion and exclusion criteria. The reports included in our evaluation were categorised based on the year of publication, type of publication, and language. The selection criteria were based on research outcomes, methodology, methods, and context.

For the review, records had to meet four criteria. They had to be peer-reviewed empirical studies on using ICT in MCI response situations, available in full text in English, based on the concept of public health response to natural disasters and other MCIs using ICT, and published in 2012 or later.

### 3.2. Sources of information

A comprehensive literature search was conducted in the PubMed, ProQuest, Scopus, ScienceDirect, Web of Science, and Google Scholar databases. The references and relevant data from the identified articles were exported to Microsoft Excel version 16.65 (365 for Mac).

More than 200 identified records were systematically evaluated using the above inclusion criteria. An additional manual literature search was conducted in the Google Scholar database in March 2022 using the snowball method. The references identified through this additional search did not meet the previously mentioned criteria.

### 3.3. Literature search

The records were retrieved from the mentioned databases on February 8, 2022. The keywords were grouped using the Boolean operators "AND", “OR,” and “NOT.” We used the following search terms: ((“crisis response” OR “disaster medicine” OR “disaster planning” OR “mass casualty incident” OR “major incident”) AND (“triage” OR “case management” OR “decision support”) AND (“artificial intelligence” OR “AI” OR “software” OR “technology”) AND (“ethics” OR “opportunities” OR “risk”) NOT (“terrorism*”)). We explicitly excluded all articles describing MCI caused by terrorist activities. The search terms were used in the PubMed, ProQuest, Scopus, ScienceDirect, and Web of Science databases. In the Scopus database, the search terms were searched in the record of each record’s title, abstract, and keywords (TITLE-ABS-KEY). Due to the search limitation in the ScienceDirect database imposed by the maximum number of Boolean operators (8), we used an adapted search term: ((mass casualty incident” OR “major incident”) AND (“triage” OR “case management” OR “decision support”) AND (“artificial intelligence” OR “software”) AND (“ethics”) NOT (“terrorism”)). Table 1 shows the number of articles found in each database. Most articles were found in the ProQuest (97) and Scopus (85) databases.

## 4. Results

### 4.1. Study selection

Fig. 1 shows the steps of the publications selection process (e.g., identification, review, and inclusion), the number of records included and excluded at each stage, and the final number of records selected for systematic review.

A total of 236 records were gathered by searching five databases using five keyword combinations. After eliminating duplicates and non-English records, 174 records were screened based on their titles and abstracts. Of these, 143 were excluded as they did not meet the eligibility criteria. The remaining 31 records were reviewed in detail, and 16 studies were excluded based on their nature and scope. Finally, 15 records were found to be eligible and were analysed carefully.

None of the included studies directly examine the impact of ICT on the performance of rescue teams during an actual MCI; instead, they focus on simulations. This is because the use and empirical testing of advanced ICT for medical teams during an MCI usually starts with simulations, and no studies have been conducted in real-life situations. This article analysed only academic studies published in the last ten years up to 2022. The literature search included only publicly accessible articles and excluded unpublished materials and case studies.

### 4.2. Study characteristics

The main characteristics of the records [26–40], identified in the scientific journal, are summarised in Table 2. The scope of medical teams in MCIs (floods, hurricanes, and fires) and the context of hazardous materials (HazMat) or chemical, biological, radiological, nuclear, and explosive (CBRNE) events are summarised.

Most studies were conducted in the United States (8), followed by the United Kingdom (2), Spain (2), Japan (1), Canada (1), Malaysia (1), China (1), Korea (1), and Switzerland (1). An important finding of our literature review is that there is a lack of research published in Europe that has thoroughly investigated the effectiveness of ICT use in MCI simulations compared to traditional pen-and-paper training. Evidence of its effectiveness could support the advantage of conducting ICT-based simulations.2.

A total of seven journal articles, seven dissertations, and one book section were included in the final review. Most of these records were published in 2021 (4), 2019 (3), followed by 2017 and 2014 (2), and 2022, 2018, 2016, and 2015 (1).

All identified studies focus on using ICT in MCIs and crisis management by EMTs. It presents findings from fifteen papers highlighting how these techniques can improve MCI management during MCIs through real-time tracking of patient information, decision-making processes, user acceptance, and resource planning applications.

***Simulation systems*** have proven to be invaluable for disaster response teams. They enable teams to coordinate effectively and respond to complex scenarios. For instance, a multi-agent simulation system was developed to evaluate disaster response team coordination, identify areas for improvement, and enhance overall performance [41,42]. ***Training*** is an integral aspect of disaster preparedness. A socio-technical training simulation system, such as SIMEOC, effectively improves crisis management. It enhances the preparedness of emergency personnel, fosters collaboration across jurisdictional boundaries, and is cost-effective [43,44].

Reddy et al. [45] highlighted ***ICT in disaster management, which involves improved effectiveness and efficiency in decision-making and allocating injured patients*** in hospitals using ICT. Coordinating EMTs and emergency department teams relies on effective information and communication technology systems. Challenges in this area include the ineffectiveness of current ICT systems, a lack of common ground, and issues with information flow.

***Use of drones in triage:*** In complex emergencies with physical, chemical, or biological risks, drones equipped with the Aerial Remote Triage System offer a unique solution for performing triage. This system prioritises patients based on criteria such as major bleeding, consciousness, and signs of life, allowing for efficient resource allocation and life-saving interventions [42].

Two analysed papers highlight the potential of ICT techniques, particularly AI and visual analytics, in improving disaster management during MCIs. These techniques can enhance situational awareness, automate data collection and analysis, and aid in developing effective response strategies.

As highlighted by Abid et al. [46], ***artificial intelligence*** (AI) is crucial in disaster management. By automating tasks like data collection and analysis, AI can enhance the accuracy and timeliness of the information. Additionally, it enables the development of more efficient response strategies, including early warning systems and predictive modelling for disaster spread. Research [46] has shown that AI has the potential to enhance disaster management significantly. AI can be utilised for the accurate and timely provision of information, automating data collection and analysis processes, and developing more effective strategies for disaster response.

Eaglin et al. [47] discuss the importance of understanding large and complex datasets to improve situational awareness for timely decisions in critical environments. These environments include emergency evacuations, indoor routing during emergencies, disaster planning for critical infrastructure and first responders, coastal planning using LiDAR analysis, and health-related analysis using social media data. The Author presents innovative work on real-time interactive visual analytics applications in these areas, highlighting techniques, systems, and tools from various disciplines, such as GPU computing for real-time analysis and machine learning for interactive analysis on mobile and web platforms.

Situational awareness is crucial for effective disaster response. Scalable, situationally aware visual analytics and applications have been highlighted as essential tools. These applications can provide better awareness and informed decision-making in critical environments, including emergency evacuations, indoor routing, and large-scale infrastructure planning [47].

While ICT techniques have significantly improved MCI management, they are not without limitations. Some of the potential challenges include: 1) *Reliability of Technology:* In some cases, the technology may fail during a disaster, disrupting telecommunication services and hindering disaster management efforts [48]. 2) *Data Overload:* The use of big data analytics and AI can sometimes lead to an overload of information, making it challenging to extract relevant and timely insights [49]. 3) *Access to Technology:* Not all regions or individuals have equal access to the necessary technology, which can create disparities in disaster management efforts [50]. 4) *User Acceptance:* There can be resistance to adopting new technologies, particularly among those not tech-savvy [3]. Additionally, integrating and coordinating multiple data sources can be complex and require significant interoperability challenges [51]. 5) *Privacy Concerns:* ICT techniques often involve collecting and analysing personal data, which can raise privacy concerns [51]. 6) *Cost:* Implementing and maintaining ICT infrastructure can be costly, which might be a limiting factor for some regions or organisations [52].

Overall, the review identified three themes: 1) the medical team's response to an MCI, 2) the simulation of MCIs and 3) the digitisation of MCI workflows, as shown in Table 2.

The ***medical team's response to an MCI*** is addressed in seven records [26,27,29,31–33,39]. A Swiss study [33] addresses an MCI due to a chemical, biological, radiological, nuclear, or explosive event (CBRNE). Two studies address MCI modelling and simulation in advance of the emergency response model. The first study [53] addresses the risks of floods and wildfires, and the second study [30] addresses the risk of tsunamis, which in turn cause flooding in coastal areas. Seven records address the area of ***MCI simulation*** [29,31,32,38–40,54]. **Digitisation of MCI work workflows** is covered in 11 records [26,29,30,32,36,38–40,53–55]. Also relevant to this systematic review are two studies from 2021. The first article [29] addresses the importance of perceptions of using augmented reality (AR) and virtual reality (VR) to support learning and training for emergency responders' actions during MCIs. The researchers

investigated participants' perceptions of virtual or augmented simulation methods in training personnel in crisis response situations. The study aimed to examine, compare and highlight the *differences between traditional and virtual simulation training* methods. As one of its specific outcomes, this study offers guidelines on how rescue teams perceive acting in stressful situations through virtual training solutions. The study concludes that participants in virtual simulation-based training develop better skills, higher levels of performance, and longer-term knowledge retention compared to other training methods. The second article [30] addresses the *concept* of AI) to support the management of natural disasters in the case of tsunamis and flooding in coastal regions. The article does not include the concept of medical team deployment. However, it provides an overview of available applications that can help manage large-scale natural disasters. According to the authors, using AI is crucial in all phases of disaster management as it results in a faster and better response.

Gormley et al. [56] provide a systematic review of ICT interactions between EMTs and find limited research in this area, identifying only fifteen relevant studies. Communication failures were observed among EMTs due to poor telecommunications infrastructure affected by challenging weather conditions [57–59]. Mobile phones were preferred over other systems for their multi-functionality [60–62].

The reported effective use of social network platforms (Twitter, WhatsApp) during emergencies includes real-time communication capacity, coordination and contact, information sharing, and accessibility [63–65]. However, technical issues and the spread of false information are factors to consider [63,64]. According to Gormley et al. [56], there is a need for improved information sharing between EMTs to enhance preparedness and coordination, as well as more disaster simulation exercises for EMTs. Future research should consider incorporating perspectives from emergency operations center staff to comprehensively explore EMT responses during emergencies.

A Japanese [32] article on the digitisation of MCI work processes explores using electronic health records in MCI situations. In a large-scale MCI simulation training, the researchers *compared traditional pen-and-paper work with electronic health records implemented through a cloud service*. The group using electronic health records took an average of 23.5 min to complete patient health records, while the pen-and-paper group took 41 min. The results suggest that the group that used an electronic health record took significantly less time to act than the control group.

The digitisation of MCI workflows involves using ICT to improve EMT's efficiency and effectiveness [32]. The benefits of digitisation include improved communication, real-time updates, and better situational awareness. Some technologies that have transformed emergency response teams' operations include digital incident response playbooks, intelligent patient monitoring, intelligent triage, and smart surveillance tech. Digitisation enhances the efficiency of medical care in MCI by improving response time and decision-making capabilities. It allows for better resource allocation, command center establishment, and integration of advanced technologies such as the Internet of Things, Big Data, and machine learning [66]. However, it is important to note that the use of ICT in MCI workflows has mainly been studied in simulations rather than real-life settings. Therefore, further research is needed to fully understand the impact and effectiveness of digitisation in real-world MCI.

Technologies can change how EMTs operate in the context of MCI. The use of ICT in MCI workflows brings various benefits, such as real-time data availability, improved communication and coordination, better decision-making processes, and enhanced resource allocation. These changes have generally improved the efficiency and effectiveness of emergency response teams [67].

It is essential to recognise that adopting ICT in MCI workflows may face challenges and resistance to change. Some emergency response teams may lack the infrastructure or resources to implement ICT [66]. This can result in a digital divide and hinder overall workflow effectiveness [68]. Data security and privacy concerns when handling sensitive patient information online can also arise [69]. Integrating ICT may require additional training and education for personnel to utilise new technologies [70].

Using the snowball method (i.e., by examining the references of the identified studies), we identified an additional article by Park [71], which explored the development and evaluation of an e-triage tag system, including the limitations of paper triage tags, the development process of the triage sensor and app, the evaluation of the system based on various criteria, and the simulation of the system in virtual scenarios. The study focuses on improving the triage process by providing real-time monitoring and recording of vital signs using a triage sensor and accompanying app.

The results highlight the system's effectiveness in reducing triage time and improving survival rates in MCI scenarios. The author calls for implementing proven ICT solutions like the e-triage tag system to enhance MCI response efforts and promote systematic approaches to MCI management.

To ensure proper scope and coordination among responders during MCIs, it is crucial to consider the role of ICT. This involves utilising real-time data, communication tools, and decision-making support systems to enhance collaboration and effectiveness within emergency response teams at the scene of MCI.

Wondim [72] highlights the impact of next-generation wireless internet and geo-positioning technologies on communication, information management, and disaster response. Mostafa et al.'s [73] study used mobile health tools and design thinking approaches to improve emergency response systems. Hu and Kapucu [73] emphasise aligning ICT utilisation with organisational objectives and roles within emergency management networks. Hasse et al. [74] demonstrate how ICT and social networks facilitate the formation of competent teams for emergency response.

Aminoff [75] proposes integrating ICT to improve coordination in crisis management, providing models for understanding its impact. Mitsusada et al. [76] study demonstrates the effectiveness of ICT in monitoring emergency medical care and optimising the allocation of injured individuals to hospitals. Tarchi et al. [77] introduce joint communication and computing optimisation through ICT to enhance resilience, response speed, and adaptability during MCIs.

Overall, research supports the crucial role of ICT in improving coordination and various aspects of emergency response in MCIs. However, it is essential to note that the available evidence in these studies is limited and further research is needed to understand the

effectiveness of ICT in MCI management. Additionally, there is a lack of research specifically addressing the use of ICT to support on-site emergency medical services during real-case MCI management. Therefore, more studies are needed to scope the potential of ICT in enhancing the efficiency and coordination of on-site EMTs in MCIs.

One of the key findings of our literature review is that no published European Union study between 2012 and 2022 has examined the use of ICT in simulating an MCI. A UK study [53] from 2018 only explores the concept of digitisation, but not MCIs or simulation. A Swiss study [33] from 2019 and a Spanish study [27] from 2021 examine the concept of MCI without any association with simulation and ICT.

Researchers in the UK [53] have developed *a simulation system for crisis scenarios based on a video game*. In crisis management and disaster planning, serious simulation in video games offers excellent potential for rescue teams to integrate multidisciplinary techniques such as disaster modelling, visualisation, interaction, communication, and environmental simulation assessment. In digitisation, US researchers [54] are developing evacuation plans for large buildings and *digitising disaster management plans accessible through mobile cloud* services (phones, tablets). In the area of digitisation in the hospital sector, the Crisis Game for Scenario Design and Agent Modelling Simulation was developed by US researchers [38] as a virtual operating centre and practice simulator in emergency medicine. This online crisis information management system allows emergency centre authorities and personnel to share information securely and in real-time.

***All three topics together*** (medical team action in MCIs, MCI simulation, and digitisation of MCI work processes) have only been covered in three records over the last ten years [29,32,39]. In answering the research question, "Can the use of ICT and MCI protocols provide better results than pen-and-paper approaches?" we reached the following conclusions: the results of our literature review show that all existing research on the benefits and support of digital transformation in MCI has only been studied in simulations and not in real-life settings. Traditional pen-and-paper documentation methods are still used. Conversely, ICT solutions are not used in real-life settings as they are rarely tested, and there is a lack of specific software development. Experience shows that resistance to or fear of change is one of the most significant barriers to digital transformation. Traditional business systems in the private and public sectors struggle to change their business models comprehensively and quickly [78]. This is because digitisation is inherently a highly interdisciplinary problem that combines individuals' and organisations' perspectives and interests. Therefore, objective representation of the problem, evaluation of the benefits, and coordination of the actors involved in the process are particularly challenging. Consequently, there is an urgent need for approaches and system tools that can be understood by all those involved in the digitisation process, from technology and ICT experts to managers and users.

## 5. Discussion

### 5.1. Summary of evidence

"Digitisation and decision making" opens a new field in the context of ICT in MCIs. The issue of decision-making has two facets. On the one hand, it is performed by human beings with limited rationality in thinking and decision-making, which makes it subject to human error. On the other hand, ICT is supposed to help make objective decisions. This aspect is unsurprising, considering that opinions differ widely, and there is no consensus on the need for digital transformation. This lack of digital thinking and government institutions' disinterest in adopting new digital standards and taking the initiative for such changes also ensures the disinterest of ICT developers in this field [78]. The results of our literature review indicate that the benefits of ICT use in realistic MCI settings have not yet been sufficiently explored. This can be explained by the relatively low incidence of MCIs, making determining its effectiveness difficult.

One of the most evident findings from our analysis relates to the different meanings researchers attribute to the benefits of using ICT to support MCI management procedures. Thus, although 11 records (73.3 %) discuss the importance of digitising MCI workflows, an operational study of the actual benefits of the final ICT is currently not possible. The actual benefits have only been/can only be studied in simulated MCI situations. Robison's study [36], for example, presents a structured reflection on various missed opportunities in the history of ICT and contrasts these cases to moments when innovation has proven to be substantially and profitably disruptive to business models and human practice. Redford [29] and Hainonen [79] claim that the emergence of platform-based VR technologies for disaster preparedness and response offers significant potential advantages over other traditional forms of training and is gaining acceptance.

According to an American study [29], VR's immersive and participatory nature provides a unique realistic quality of training typically impossible in classrooms or web-based modalities while offering a significant cost advantage over large-scale real-world exercises. Comparative research between VR-based and traditional disaster training modalities shows a need to examine the various aspects of realism, cost, and disaster preparedness. For organisations, the ultimate goal would be a VR/AR system controlled solely by thought to mimic real-world scenes in a crisis response activity [80]. The increasing implementation of VR-based training for MCI preparedness and response, either alone or in combination with other training modalities, capitalises on these benefits and is a highly anticipated development [81]. For example, remote triage by drones in MCIs may be helpful for the initial and rapid assessment of complex health emergency scenarios with difficult or delayed access due to physical barriers or CBRNE situations [27].

Another important finding of this study is the paucity of evidence on the impact of digital protocols on MCI outcomes, which we sought to address with our research question. The current evidence from MCI simulations (e.g. the Japanese survey [32]) only indicates the effectiveness of outcomes compared to traditional pen-and-paper training. The Japanese study [32], which focused on the effectiveness of healthcare providers' actions in simulating an MCI using digitised workflows, demonstrated the benefits of capturing and sharing information digitally.

This literature review raises awareness of the importance of proper training and education on using ICT to support MCI

management. The lack of ICT-supported training in an environment where multiple people can work together simultaneously undermines the ability of participants to collaborate effectively with other agencies (police and firefighters) during an MCI. Consequently, the need for new ICT to assist crisis intervention teams in decision-making would help increase the efficiency of the resources provided and the survival rate of the injured or ill [10,78].

However, this contrasts with the results of a Canadian quasi-experiment [26], which examined the benefits of a triage protocol called Rapid Assessment Triage for Emergency Department/Urgent Care (RATE), developed specifically for use in emergency departments during MCIs and compared its infographic with an e-learning module. The study found no significant difference between the e-learning module and the traditional learning mode.

Virtual simulation training can be beneficial in providing EMTs and other rescue personnel opportunities for increased skill acquisition and knowledge retention compared to other training modalities. Additionally, learning motivation within a more social context was observed with virtual simulation training. Several studies [82–88] discuss the benefits and limitations of using a socio-technical training simulator for training emergency managers for crises in a virtual environment.

The studies included in our literature review examined various technologies and strategies to enhance disaster management and emergency response. These include socio-technical training simulators for emergency managers, immersive learning-based simulations for medical scenarios [38], and the role of AI [30] in MCI management. Real-time interactive visual analytics [35] offers insights from social media for efficient evacuations, infrastructure assessment, and data integration. A multi-agent simulation system [39] assesses disaster response team coordination and performance. Triage tools [33] and techniques improve decision-making in mass casualty incidents. A computer-based system for patient record management [89] and the impact of information sharing on disaster medicine in Japan [32] are discussed. Lastly, the effectiveness of simulations in developing ethical reasoning in disaster management education is examined [31]. These technologies and strategies collectively hold the potential to significantly advance disaster management by enhancing training, decision-making, coordination, response efficiency, and overall crisis management.

Positive results were reported for using a socio-technical training simulator in training emergency managers for crises in a virtual environment [82–85,87,88]. The papers highlight the benefits of using a simulator, such as increased situational awareness, improved decision-making skills, and enhanced communication and collaboration among team members. The studies also suggest that simulators can improve performance during real-world crises. However, additional research is recommended to address the potential limitations and enhance the effectiveness of simulators. Redford et al. [29] stress the need for studies that improve simulator realism and incorporate more complex scenarios. Moreover, exploring different training contexts and diverse groups of emergency managers in relation to simulators is also suggested by Redford [29] as a future direction for investigation.

When an MCI occurs, the environment is complex, stressful, and unique. Under normal circumstances, there is an opportunity to learn from actual events, which may differ in an MCI. Therefore, there is an urgent need for prior practical training to ensure that the effectiveness of actions in real-life situations meets the expected standards. For response teams to achieve satisfactory knowledge, numerous hands-on exercises are required, which are expensive and of questionable effectiveness. However, 90 % of all training activities can be replaced by digitising training for MCI logistics, resulting in better decisions than a VR-based simulation [38] or a video game [53].

## 6. Limitations

A major limitation of this study is the lack of direct research on how ICT affects rescue teams' performance in real-life MCI operations. While the systematic review provides insights into potential ICT applications for MCI management, our understanding of its practical effectiveness is limited due to a need for more empirical investigations in real-world scenarios. To address this knowledge gap, future studies should prioritise directly assessing the impact of advanced ICTs, such as simulation systems and decision support tools, on EMTs during MCIs.

The literature review focuses on academic studies published in the last decade. However, it is important to note that there may be relevant unpublished works and case studies that could provide valuable insights into the topic. The exclusion of non-academic sources might limit the comprehensiveness of the review and fail to capture practical implementations or advancements in ICT usage during MCIs. Future research should consider incorporating a wider range of sources, including unpublished literature and case studies, to enhance our understanding of the impact of ICT in MCI management.

## 7. Conclusions

ICT has the potential to improve crisis management, particularly in the context of EMTs actions during MCI. Further research is needed to determine if digital transformation optimises medical teamwork through advanced ICT, leading to more effective management decisions and increased chances of survival in MCIs. This study provides evidence for future researchers to conduct experimental research, especially within Europe.

In summary, these studies collectively unveil the multifaceted applications of ICT in mitigating the complex challenges inherent in MCI. From innovative triage protocols and aerial surveillance using drones to telehealth systems, advanced training methodologies such as AR/VR, AI, and machine learning for data analysis, and ethical considerations surrounding high-fidelity simulations and game-based training, these findings contribute to a comprehensive understanding of how ICT can augment preparedness, response, and training for MCI. As the academic community continues to delve into this domain, the integration of ICT remains pivotal in reshaping disaster response emergency response and management paradigms, ultimately bolstering societal resilience in the face of unforeseen calamities.

Several technologies and strategies show promise and require deeper investigation. Further research is required to enhance

response efficiency during MCIs by integrating advanced tools like communication, data analytics, and decision support systems. Some of these technologies and strategies are: 1) *Leveraging Emerging Information Technologies* (e.g., IoT, Big Data, social media, and machine learning) to enhance early warning systems for MCI through improved visualisation, analysis, and prediction; 2) *Research in this field should focus on integrating various ICT systems* to support seamless coordination among MCI response professionals, facilitating data sharing and communication; 3) *Ongoing ICT Evolution* to effectively meet changing needs through real-time communication; 4) *Development of AR platform for MCI management response* by integrating wearable devices, virtual beacons, and sensor network nodes to support coordination between incident commanders and paramedics; 5) *Smart glasses* to enable EMS responders to work with both hands while assessing patients and can be utilised for telemedicine and AR functions to improve triage accuracy and efficiency; 6) *Utilisation of Drones and Smart Surveillance* for real-time data collection and situational awareness during MCI responses.

Digital technologies and strategies have shown great potential in enhancing the efficiency and effectiveness of emergency response teams. However, their widespread adoption faces several challenges, including ensuring data quality, security, privacy, and ethics, addressing digital divides and inequalities, managing complexity and uncertainty, and balancing trade-offs and costs. Therefore, further research is necessary to fully comprehend the potential.

## Funding

The authors received no financial support for this article's research, authorship and/or publication.

## CRediT authorship contribution statement

**Primož Režek:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Boštjan Žvanut:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing.

## 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.

## Data availability

No data was used for the research described in the article.

## References

[1] J.O. Park, S.D. Shin, K.J. Song, K.J. Hong, J. Kim, Epidemiology of emergency medical services-assessed mass casualty incidents according to causes, J. Kor. Med. Sci. 31 (2016) 449, https://doi.org/10.3346/jkms.2016.31.3.449.
[2] J. Thompson, M. Rehn, H.M. Lossius, D. Lockey, Risks to emergency medical responders at terrorist incidents: a narrative review of the medical literature, Crit. Care 18 (2014) 521, https://doi.org/10.1186/s13054-014-0521-1.
[3] A. Holgersson, Review of on-scene management of mass-casualty attacks, J. Hum. Secur. 12 (2016) 91–111, https://doi.org/10.12924/johs2016.12010091.
[4] W. Yu, Y. Lv, C. Hu, X. Liu, H. Chen, C. Xue, L. Zhang, Research of an emergency medical system for mass casualty incidents in Shanghai, China: a system dynamics model, Patient Prefer. Adherence ume 12 (2018) 207–222, https://doi.org/10.2147/PPA.S155603.
[5] I.P. Guide, Managing the Emergency Consequences of Terrorist Incidents, 2002.
[6] E.R. Frykberg, Principles of mass casualty management following terrorist disasters, Ann. Surg. 239 (2004) 319–321, https://doi.org/10.1097/01.sla.0000116001.97770.ce.
[7] P. Hoth, J. Roth, D. Bieler, B. Friemert, A. Franke, T. Paffrath, M. Blätzinger, G. Achatz, And the Deployment, Disaster, Tactical Surgery Section of the German Trauma Society, Education and training as a key enabler of successful patient care in mass-casualty terrorist incidents, Eur. J. Trauma Emerg. Surg. 49 (2023) 595–605, https://doi.org/10.1007/s00068-023-02232-w.
[8] G. Friese, Principles of Mass Casualty: Response to Terrorist Attacks, EMS World, 2007. https://www.hmpgloballearningnetwork.com/site/emsworld/article/10321585/principles-mass-casualty-response-terrorist-attacks.
[9] S.A. Turris, A. Lund, R.R. Bowles, An analysis of mass casualty incidents in the setting of mass gatherings and special events, Disaster Med. Public Health Prep. 8 (2014) 143–149, https://doi.org/10.1017/dmp.2014.24.
[10] D. Dujić, B. Simčič. Smernice za delovanje sistema nujne medicinske pomoči ob množičnih nesrečah, Ministrstvo za zdravje, Sektor za kakovost in varnost sistema zdravstvenega varstva, Ljubljana, 2013, pp. 23–25.
[11] B. Adini, L. Aharonson-Daniel, A. Israeli, Load index model: an advanced tool to support decision making during mass-casualty incidents, J. Trauma Acute Care Surg. 78 (2015) 622–627, https://doi.org/10.1097/TA.0000000000000535.
[12] O. Amram, N. Schuurman, N. Hedley, S.M. Hameed, A web-based model to support patient-to-hospital allocation in mass casualty incidents, J. Trauma Acute Care Surg. 72 (2012) 1323–1328, https://doi.org/10.1097/TA.0b013e318246e879.
[13] M.-R. Khaje-Aminian, S.M. Hosseini Boroujeni, Casualty distribution in emergencies: some critiques of load index model, J. Trauma Acute Care Surg. 79 (2015) 884, https://doi.org/10.1097/TA.0000000000000846.
[14] S. Gastaldi, M. Horlait, Health care organizations' interoperability during multi-organizational disaster management: a scoping review, Prehospital Disaster Med. 37 (2022) 401–408, https://doi.org/10.1017/s1049023x22000516.
[15] L. Clarkson, M. Williams, EMS mass casualty triage, in: StatPearls, StatPearls Publishing, Treasure Island (FL, 2023. http://www.ncbi.nlm.nih.gov/books/NBK459369/. (Accessed 7 October 2023).
[16] Hospital Medical Surge Planning for Mass Casualty Incidents, (n.d.). https://www.urmc.rochester.edu/medialibraries/urmcmedia/flrtc/documents/wny-hospital-medical-surge-planning-for-mass-casualty-incidents.pdf (accessed October 7, 2023) 1-11.
[17] Triage During a Mass Casualty, (n.d.). https://files.asprtracie.hhs.gov/documents/epimn-module-1-triage-during-a-mass-casualty-incident.pdf (accessed October 7, 2023) 15-27.
[18] Southwest Virginia Mass Casualty Incident Response Guide, (n.d.). http://southwest.vaems.org/index.php?Itemid=302&alias=483-mci-plan-final&category_slug=regional-plans&option=com_docman&view=download (accessed October 7, 2023) 3-14.

[19] Operational Templates and Guidance for EMS Mass Incident Deployment, (n.d.). https://www.usfa.fema.gov/downloads/pdf/publications/templates_guidance_ems_mass_incident_deployment.pdf (accessed October 7, 2023) 63-73.
[20] S.K. Sood, K.S. Rawat, A scientometric analysis of ICT-assisted disaster management, Nat. Hazards 106 (2021) 2863–2881, https://doi.org/10.1007/s11069-021-04512-3.
[21] C.-L. Kao, L.-C. Chien, M.-C. Wang, J.-S. Tang, P.-C. Huang, C.-C. Chuang, C.-L. Shih, The development of new remote technologies in disaster medicine education: a scoping review, Front. Public Health 11 (2023) 1029558, https://doi.org/10.3389/fpubh.2023.1029558.
[22] K. Matthews, 6 Ways Tech Has Improved Responses to Mass Casualty Incidents, Health IT Outcomes, 2019. https://www.healthitoutcomes.com/doc/ways-tech-has-improved-responses-to-mass-casualty-incidents-0001.
[23] A.T. Chatfield, J.J. Gonzalez, T. Comes, Introduction to ICT-Enabled Crisis, Disaster and Catastrophe Management Minitrack, IEEE Computer Society, 2014, 1946–1946.
[24] A. Liberati, D.G. Altman, J. Tetzlaff, C. Mulrow, P.C. Gøtzsche, J.P.A. Ioannidis, M. Clarke, P.J. Devereaux, J. Kleijnen, D. Moher, The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration, PLoS Med. 6 (2009) e1000100, https://doi.org/10.1371/journal.pmed.1000100.
[25] Covidence - Better Systematic Review Management Software, 2022. https://get.covidence.org/covidence-vs-distillersr. March 13, 2022.
[26] G. Reay, J.A. Rankin, C. Dobson, K. Campbell, Mass casualty triage for the Emergency Department using the RATE protocol: validation and results of a quasi-experiment, Int. Emerg. Nurs. 61 (2022) 101124, https://doi.org/10.1016/j.ienj.2021.101124.
[27] C. Álvarez-García, S. Sixto Cámara-Anguita, J.M. López-Hens, N. Granero-Moya, M.D.D. López-Franco, I. María-Comino-Sanz, S. Sanz-Martos, P.L. Pancorbo-Hidalgo, Development of the Aerial Remote Triage System using drones in mass casualty scenarios: a survey of international experts, PLoS One 16 (2021), https://doi.org/10.1371/journal.pone.0242947.
[28] M. Tresenriter, J. Holdaway, J. Killeen, T. Chan, C. Dameff, The implementation of an emergency medicine telehealth system during a pandemic, J. Emerg. Med. 60 (2020) 548–553, https://doi.org/10.1016/j.jemermed.2020.11.026.
[29] A.C. Redford, Perceptions of the Use of Augmented and Virtual Reality Supporting Emergency Response Education and Training, Capella University, 2021. D.I.T. https://www.proquest.com/dissertations-theses/perceptions-use-augmented-virtual-reality/docview/2496310039/se-2?accountid=31479.
[30] K.A. Sheikh, N. Sulaiman, W.C. Shiau, U. Nazir, M. Abid, H. Han, A. Ariza-Montes, A. Vega-Munoz, Toward an integrated disaster management approach: how artificial intelligence can boost disaster management, Sustainability 13 (2021) 12560, https://doi.org/10.3390/su132212560.
[31] S. Greco, E.J. Lewis, J. Sanford, E.M. Sawin, A. Ames, Ethical reasoning debriefing in disaster simulations, J. Prof. Nurs. 35 (2019) 124–132, https://doi.org/10.1016/j.profnurs.2018.09.004.
[32] Y. Kondo, M. Ichikawa, H. Kondo, Y. Koido, Y. Otomo, Current disaster medicine in Japan and the change brought by information sharing, J. Disaster Res. 14 (2019) 292–302, https://doi.org/10.20965/jdr.2019.p0292.
[33] C. Bertrand, E. Lecarpentier, F. Herodin, F. Dorandeu, Triage issues in a CBRNE crisis: experiences from European projects, in: D. OMathuna, I. Beriain (Eds.), ETHICS LAW Chem. Biol. Radiol. Nucl. Explos. CRISES, 2019, pp. 173–183, https://doi.org/10.1007/978-3-030-11977-5_14.
[34] P. Praiwattana, Investigation into Game-Based Crisis Scenario Modelling and Simulation System, Liverpool John Moores University (United Kingdom), 2018. Ph.D. https://www.proquest.com/dissertations-theses/investigation-into-game-based-crisis-scenario/docview/2495344552/se-2?accountid=31479.
[35] T. Eaglin, Scalable, Situationally Aware Visual Analytics and Applications, The University of North Carolina at Charlotte, 2017. Ph.D. https://www.proquest.com/dissertations-theses/scalable-situationally-aware-visual-analytics/docview/1889562309/se-2.
[36] J.M. Robinson, Sustaining Innovations and Disruptive Technologies: Implications for Mobile Health (Mhealth) Care Platforms, The University of Texas at Dallas, 2017. Ph.D. https://www.proquest.com/dissertations-theses/sustaining-innovations-disruptive-technologies/docview/2018410242/se-2?accountid=31479.
[37] C.L. Price, S.J. Brace-McDonnell, N. Stallard, A. Bleetman, I. Maconochie, G.D. Perkins, Performance characteristics of five triage tools for major incidents involving traumatic injuries to children, Injury 47 (2016) 988–992, https://doi.org/10.1016/j.injury.2015.10.076.
[38] C.M. Nikolai, SimEOC: A Virtual Emergency Operations Center (VEOC) Simulator for Training and Research, Ph.D., University of Notre Dame, 2015. https://www.proquest.com/dissertations-theses/simeoc-virtual-emergency-operations-center-veoc/docview/1738054099/se-2?accountid=31479.
[39] M. Hashemipour, A Multi-Agent Simulation System to Evaluate the Disaster Response Team Coordination and Performance, The George Washington University, 2017. Ph.D. https://www.proquest.com/dissertations-theses/multi-agent-simulation-system-evaluate-disaster/docview/1930990815/se-2?accountid=31479.
[40] L. Wu, Dynamic Procedure Aids Support Crisis Attention, Stanford University, 2014. Ph.D. https://www.proquest.com/dissertations-theses/dynamic-procedure-aids-support-crisis-attention/docview/2499396178/se-2?accountid=31479.
[41] C.L. Price, S.J. Brace-McDonnell, N. Stallard, A. Bleetman, I. Maconochie, G.D. Perkins, Performance characteristics of five triage tools for major incidents involving traumatic injuries to children, Injury 47 (2016) 988–992.
[42] C. Álvarez-García, S. Cámara-Anguita, J.M. López-Hens, N. Granero-Moya, M.D. López-Franco, I. María-Comino-Sanz, S. Sanz-Martos, P.L. Pancorbo-Hidalgo, Development of the Aerial Remote Triage System using drones in mass casualty scenarios: a survey of international experts, PLoS One 16 (2021) e0242947, https://doi.org/10.1371/journal.pone.0242947.
[43] C.M. Nikolai, SimEOC: a Virtual Emergency Operations Center (VEOC) Simulator for Training and Research, University of Notre Dame, 2015.
[44] A.C. Redford, Perceptions of the Use of Augmented and Virtual Reality Supporting Emergency Response Education and Training, 2021.
[45] M.C. Reddy, S.A. Paul, J. Abraham, M. McNeese, C. DeFlitch, J. Yen, Challenges to effective crisis management: using information and communication technologies to coordinate emergency medical services and emergency department teams, Int. J. Med. Inf. 78 (2009) 259–269.
[46] S.K. Abid, N. Sulaiman, S.W. Chan, U. Nazir, M. Abid, H. Han, A. Ariza-Montes, A. Vega-Muñoz, Toward an integrated disaster management approach: how artificial intelligence can boost disaster management, Sustainability 13 (2021) 12560.
[47] T. Eaglin, Scalable, Situationally Aware Visual Analytics and Applications, 2017.
[48] U. Escap, Enhancing E-Resilience of ICT Infrastructure: Gaps and Opportunities in Disaster Management, 2015.
[49] A. D'Andrea, P. Grifoni, F. Ferri, Discussing the role of ICT in sustainable disaster management, Sustainability 14 (2022) 7182, https://doi.org/10.3390/su14127182.
[50] Unacademy Disaster Management and Technology, https://unacademy.com/content/upsc/study-material/disaster-management/disaster-management-and-technology (accessed 23 October 2023).
[51] ITU, A Safer, More Resilient World: Reducing Disaster Risks with AI, ITU Hub, 2020. https://www.itu.int/hub/2020/10/a-safer-more-resilient-world-reducing-disaster-risks-with-ai/. (Accessed 23 October 2023).
[52] T. Mondal, S. Pramanik, P. Pramanik, K.N. Datta, P.S. Paul, S. Saha, S. Nandi, Emergency communication and use of ICT in disaster management, in: M. Sakurai, R. Shaw (Eds.), Emerg. Technol. Disaster Resil., Springer Singapore, Singapore, 2021, pp. 161–197, https://doi.org/10.1007/978-981-16-0360-0_10.
[53] P. Praiwattana, Investigation into Game-Based Crisis Scenario Modelling and Simulation System, Liverpool John Moores University (United Kingdom), 2018. Ph.D. https://www.proquest.com/docview/2495344552/abstract/69E96FE6DE134D58PQ/1. March 15, 2022)
[54] T. Eaglin, U. of N.C. at C., ProQuest (Firm), Department of Computing and Information Systems, Scalable, situationally aware visual analytics and applications, 2017.
[55] M. Tresenriter, J. Holdaway, J. Killeen, T. Chan, C. Dameff, The implementation of an emergency medicine telehealth system during a pandemic, J. Emerg. Med. 60 (2021) 548–553, https://doi.org/10.1016/j.jemermed.2020.11.026.
[56] K. Gormley, B. Alshehri, K. McCutcheon, G. Prue, The use of information and communication technology between emergency medical teams in emergency situations: a systematic review, Biol. Med. 14 (2022) 496.
[57] M.C. Reddy, S.A. Paul, J. Abraham, M. McNeese, C. DeFlitch, J. Yen, Challenges to effective crisis management: using information and communication technologies to coordinate emergency medical services and emergency department teams, Int. J. Med. Inf. 78 (2009) 259–269.
[58] Z. Zhang, A. Sarcevic, R.S. Burd, Supporting information use and retention of pre-hospital information during trauma resuscitation: a qualitative study of pre-hospital communications and information needs, AMIA Annu. Symp. Proc. AMIA Symp. 2013 (2013) 1579–1588.
[59] Z. Zhang, A. Sarcevic, C. Bossen, Constructing Common Information Spaces across Distributed Emergency Medical Teams, 2017, pp. 934–947.

[60] H. Yamamura, K. Kaneda, Y. Mizobata, Communication problems after the great East Japan earthquake of 2011, disaster med, Public Health Prep 8 (2014) 293–296, https://doi.org/10.1017/dmp.2014.49.
[61] H. Zhou, L. Shi, Y. Mao, J. Tang, Y. Zeng, Diffusion of new technology, health services and information after a crisis: a focus group study of the Sichuan "5.12" Earthquake, Int. J. Health Plann. Manag. 29 (2014) 115–123, https://doi.org/10.1002/hpm.2137.
[62] M. Pouraghaei, A. Jannati, P. Moharamzadeh, A. Ghaffarzad, M.H. Far, J. Babaie, Challenges of hospital response to the twin earthquakes of august 21, 2012, in East Azerbaijan, Iran, disaster med, Public Health Prep 11 (2017) 422–430, https://doi.org/10.1017/dmp.2016.153.
[63] A. Eksi, S. Celikli, G.S. Kiyan, The effects of social networking on disaster communication used by the emergency medical and rescue staff - the case of the van earthquake, J. Acad. Emerg. Med. 13 (2014) 58–61, https://doi.org/10.5152/jaem.2014.19971.
[64] V. Homier, R. Hamad, J. Larocque, P. Chassé, E. Khalil, J.M. Franc, A randomized trial comparing telephone tree, text messaging, and instant messaging app for emergency department staff recall for disaster response, Prehospital Disaster Med. 33 (2018) 471–477, https://doi.org/10.1017/S1049023X18000912.
[65] E. Skryabina, N. Betts, G. Reedy, P. Riley, R. Amlôt, UK healthcare staff experiences and perceptions of a mass casualty terrorist incident response: a mixed-methods study, Emerg. Med. J. 38 (2021) 756–764, https://doi.org/10.1136/emermed-2019-208966.
[66] F. Figueiredo, M.J.A. Gonçalves, S. Teixeira, Information technology adoption on digital marketing: a literature review, Informatics 8 (2021) 74, https://doi.org/10.3390/informatics8040074.
[67] P. Díaz, T. Onorati, M. Romano, I. Aedo, Designing affordable technologies to integrate citizens in early warning activities, in: UCAmI 2018, MDPI, 2018, p. 1253, https://doi.org/10.3390/proceedings2191253.
[68] K. Furtak, The state of functioning transport, freight forwarding and logistics companies and their responses to the pandemic crisis, Management 25 (2021) 133–152, https://doi.org/10.2478/manment-2019-0077.
[69] B. Ristevski, M. Chen, Big data analytics in medicine and healthcare, J. Integr. Bioinforma. 15 (2018) 20170030, https://doi.org/10.1515/jib-2017-0030.
[70] J.M. Fernández-Batanero, P. Román-Graván, M. Montenegro-Rueda, E. López-Meneses, J. Fernández-Cerero, Digital teaching competence in higher education: a systematic review, Educ. Sci. 11 (2021) 689, https://doi.org/10.3390/educsci11110689.
[71] J.Y. Park, Real-time monitoring electronic triage tag system for improving survival rate in disaster-induced mass casualty incidents, Healthcare 9 (2021) 877, https://doi.org/10.3390/healthcare9070877.
[72] M. Wondim, Information Communication Technologies during Emergency: Field to Hospital November, 2018, 2016, https://api.semanticscholar.org/CorpusID:188661079.
[73] Q. Hu, N. Kapucu, Information communication technology utilization for effective emergency management networks, Publ. Manag. Rev. 18 (2014) 323–348, https://doi.org/10.1080/14719037.2014.969762.
[74] D. Hasse, F.A.O. Gauthier, C.R. De Rolt, G. Hasse Klein, Coordinating emergency response by competent teams, IADIS Int. J. Comput. Sci. Inf. Syst. 13 (2018) 33–51, https://doi.org/10.33965/ijcsis_2018130103.
[75] Hedvig Aminoff, Coordination in Emergency Management from a Joint Cognitive Systems Perspective, (n.d.)..
[76] M. Mitsusada, A. Onogawa, Y. Shima, Results of lectures and training on two methods of disaster triage for local residents who are not medical personnel, Prehospital Disaster Med. 32 (2017) S240, https://doi.org/10.1017/s1049023x1700615x.
[77] D. Tarchi, V. Petrini, G.E. Corazza, A fully reconfigurable approach to emergency management, Int. J. Adapt. Resilient Aut. Syst. (IJARAS) 4 (2013) 80–100, https://doi.org/10.4018/jaras.2013010104.
[78] C. Bavec, A. Kovacic, M. Krisper, V. Rajkovic, M. Vintar, Slovenija Na Poti Digitalne Preobrazbe, Zalozba UL FRI, Ljubljana, 2019. http://zalozba.fri.uni-lj.si/bavec2019.pdf. (Accessed 3 February 2022).
[79] M. Heinonen, Adoption of VR and AR Technologies in the Enterprise, VR Ja AR Teknologioiden Adaptaatio Yritysmaailmassa, 2017. https://lutpub.lut.fi/handle/10024/144092. June 20, 2022).
[80] S.F.M. Alfalah, Perceptions toward adopting virtual reality as a teaching aid in information technology, Educ. Inf. Technol. 23 (2018) 2633–2653, https://doi.org/10.1007/s10639-018-9734-2.
[81] N. Abdulhamid Gambo, Harnessing Collaborative Technologies in Digital Disaster Response Work: an Examination of Digital Volunteers' Activities in Processing Crisis Data, Brunel University London, Thesis, 2018. http://bura.brunel.ac.uk/handle/2438/18084. June 20, 2022.
[82] P.K. Kwok, M. Yan, B.K.P. Chan, H.Y.K. Lau, Crisis management training using discrete-event simulation and virtual reality techniques, Comput. Amp Ind. Eng. 135 (2019) 711–722, https://doi.org/10.1016/j.cie.2019.06.035.
[83] F. Tena-Chollet, J. Tixier, A. Dandrieux, P. Slangen, Training decision-makers: existing strategies for natural and technological crisis management and specifications of an improved simulation-based tool, Saf. Sci. 97 (2017) 144–153, https://doi.org/10.1016/j.ssci.2016.03.025.
[84] Simulation based emergency response training, Sci. Bull. Nav. Acad. 19 (2016) 85–90, https://doi.org/10.21279/1454-864x-16-i1-015.
[85] C. Nikolai, T. Johnson, M. Prietula, I. Becerra-Fernandez, G. Madey, SimEOC, Int. J. Inf. Syst. Crisis Response Manag. 7 (2015) 1–21, https://doi.org/10.4018/ijiscram.2015010101.
[86] Pierrick Duhamel, Contribution to a Design Methodology for Crisis and Emergency Training on Hazardous Industrial Sites, (n.d.)..
[87] Ade Sutrimo, Virutal Simulation Training for Enhancing the Mental Health Preparedness of the Health Provider, Responder and Social Workforce in the Emergency and Mitigation Setting: a Literature Review, (n.d.)..
[88] A. Parush, A. Springer, Ruth Livkind, Shani Laendler, Tal Solomon, Alex Nicola, Ksenia Kaganer, Simulator and Game-Based Multi-Level Training of Cognitive Skills and EMS Teamwork in Multi-Casualty Incident Management, (n.d.)..
[89] P. Praiwattana, Investigation into Game-Based Crisis Scenario Modelling and Simulation System, Liverpool John Moores University (United Kingdom), 2018. Ph.D. https://www.proquest.com/dissertations-theses/investigation-into-game-based-crisis-scenario/docview/2495344552/se-2?accountid=31479.