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Resource Optimization and Logistics Data Governance in Mass Casualty Incidents: A Review of Emergency Medical Services and Nursing Decision-Support Systems

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Abstract

Background: Mass casualty incidents (MCIs) create immense strain on healthcare systems, requiring rapid, efficient mobilization of scarce resources. Effective coordination between field-based Emergency Medical Services (EMS) and receiving hospital nursing command is essential but often impeded by fragmented data systems.

Aim: This narrative review synthesizes literature on data-driven strategies and decision-support systems for optimizing MCI logistics, focusing on the EMS-nursing interface and the necessary data governance frameworks.

Methods: A thematic synthesis was conducted on peer-reviewed literature (2010-2024) from major databases (PubMed, CINAHL, Scopus, IEEE Xplore) using keywords related to mass casualty, resource management, decision-support, data governance, EMS, and nursing.

Results: The review identifies four key themes: 1) technological tools for real-time situational awareness; 2) predictive analytics for forecasting demand; 3) integrated decision-support systems for command decisions; and 4) foundational data governance models. Findings show a trend towards integrated dashboards and IoT-enabled tracking but reveal persistent gaps in system interoperability, governance protocols, and human-factor integration for high-stress deployment.

Conclusion: Optimal resource management in MCIs depends on interoperable, well-governed data systems that provide a shared operational picture. Advancing beyond technology to prioritize robust governance, standardized protocols, and human-centered design is crucial for transforming data into effective, ethical action that improves surge capacity and patient outcomes.

Keywords: Mass Casualty Incident, Resource Management, Decision Support Systems, Data Governance, Emergency Nursing

Introduction

The chaotic aftermath of a mass casualty incident (MCI)—defined as an event that overwhelms local healthcare resources by generating several victims large enough to disrupt normal medical services—represents the ultimate stress test for emergency and disaster preparedness systems (Lennquist, 2012). In this high-stakes environment, the effective management of finite and often scarce resources such as specialized personnel (e.g., trauma surgeons, critical care nurses), medical equipment (ventilators, ventilators, and vascular access kits), bed space (particularly in intensive care and operating theaters), and pharmaceuticals (blood products, analgesics, antibiotics) becomes a determinant of population survival and morbidity (Bazyar et al., 2022). Traditionally, resource allocation during MCIs has been guided by triage protocols, incident command system (ICS) structures, and the experience of on-scene commanders and receiving hospital leaders. However, these methods, while foundational, often rely on incomplete, delayed, or subjective information, leading to suboptimal decisions that can exacerbate the crisis (Hugelius, 2021).

The modern landscape of disaster medicine is increasingly digital, generating what some scholars term the "data-rich but information-poor" paradox in emergency response (AlAbdulaali et al., 2022). A critical nexus in this landscape exists between the mobile, decentralized operations of Emergency Medical Services (EMS) in the field and the static, institutional command centers of receiving hospitals, where nursing leadership plays a pivotal role in surge capacity activation, staff deployment, and patient flow management (Veenema et al., 2018). The seam between these two domains—the point of patient handover and logistical coordination—is frequently where information systems fail, data degrades, and critical resource decisions are made without a comprehensive, real-time operational picture (Saadatmand et al., 2023).

This narrative review, therefore, posits that optimizing resource logistics in MCIs is not merely a matter of having more resources but of having

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superior *information* about resource status, location, demand, and utilization. It aims to synthesize and critically analyze the extant literature from 2010 to 2024 on data-driven strategies and technological decision-support systems designed for resource management in MCIs, with a dedicated focus on the EMS-nursing interface. Furthermore, recognizing that data is only as valuable as it is trustworthy, accessible, and secure, this review will interrogate the nascent but crucial literature on the data governance models required to ensure the quality, integrity, and timely flow of logistical data across organizational and jurisdictional boundaries during a crisis. The central thesis is that the evolution from experience-based, reactive resource management to data-informed, proactive logistics command requires integrated technological systems underpinned by robust governance principles.

Methodology

This study employed a narrative review methodology, chosen for its suitability in synthesizing a broad, interdisciplinary body of literature to provide a comprehensive overview, identify key themes and debates, and highlight gaps in knowledge (Greenhalgh & Dijkstra, 2024). The review focused on peer-reviewed literature published in English between January 2010 and May 2024, a period marked by significant technological advancement and increasing scholarly attention to data-driven disaster management.

A systematic search strategy was executed across four major electronic databases: PubMed (for biomedical and clinical perspectives), CINAHL (for nursing and allied health literature), Scopus (for interdisciplinary coverage), and IEEE Xplore (for engineering, technology, and computing literature). Search strings combined key terms and Boolean operators: ("mass casualty" OR "disaster" OR "mass casualty incident" OR "MCI") AND ("resource management" OR "logistics" OR "supply chain" OR "surge capacity") AND ("decision support system" OR "dashboard" OR "predictive analytics" OR "real-time tracking") AND ("data governance" OR "data quality" OR "interoperability" OR "information sharing") AND ("emergency medical services" OR "EMS" OR "paramedic" OR "prehospital") AND ("nursing" OR "emergency nursing" OR "disaster nursing" OR "hospital command").

Inclusion criteria encompassed: empirical studies (qualitative, quantitative, mixed-methods), simulation and modelling studies, systematic/scoping reviews, and conceptual/theoretical papers directly addressing technological systems, data strategies, or governance frameworks for resource management in MCIs or analogous high-acuity surge events. Exclusion criteria included: articles focused solely on military contexts without civilian translation, single-case reports of specific events without generalizable analysis of systems, and articles published before 2010.

Data from selected articles were extracted thematically rather than statistically, given the narrative design. Analysis involved iterative reading, coding, and thematic grouping to identify dominant constructs, technological solutions, reported challenges, and theoretical propositions related to EMS-nursing data integration, decision-support, and governance. The findings are structured around four emergent thematic pillars that form the analytical core of this review.

The Evolution of Situational Awareness: From Radio Reports to Integrated Dashboards

The cornerstone of effective resource logistics is situational awareness (SA)—the perception of elements in the environment, the comprehension of their meaning, and the projection of their status in the near future (Endsley, 2020; Table 1 & Figure 1). In MCIs, SA for both EMS commanders and hospital nursing leaders has historically been degraded by reliance on voice radio, paper triage tags, and sequential phone calls, leading to the "fog of disaster" (Alexander, 2021).

Technological Enablers for Real-Time Asset Tracking

Contemporary literature documents a shift towards technology-enhanced SA. For EMS, this includes the deployment of Electronic Triage Tags (ETags) equipped with RFID or Bluetooth sensors, which transmit patient location, triage category, and basic physiological data to a central incident command software platform (Napi et al., 2019). Coupled with GPS tracking of ambulances and critical supply vehicles, this allows for a dynamic, map-based view of resource dispersion. Studies by Khorram-Manesh et al. (2023) and Aboualola et al. (2023) demonstrate that such systems can reduce scene-time confusion and improve the accuracy of patient tracking compared to paper-based systems. Furthermore, Internet of Things (IoT)-enabled inventories for key equipment (e.g., ventilators, hemorrhage control kits) on ambulances and in hospital stockrooms provide real-time visibility into asset availability and consumption rates, a capability highlighted as critical for managing scarce items during prolonged incidents (Seth et al., 2022).

Shared Situational Awareness Dashboards

The integration of field data with hospital capacity data is the next critical step. Shared dashboards are increasingly proposed as the technological linchpin for this integration. These cloud-based platforms aim to aggregate data from EMS E-Tags, ambulance telemetry, hospital bed management systems, and inventory databases to create a Common Operating Picture (COP) (AlAbdulaali et al., 2022). For nursing leaders in the emergency department (ED) and hospital command center, such a dashboard could project not just the number of incoming patients, but their predicted acuity, required resources (e.g., "10 patients requiring surgical intervention, 4 requiring ventilators"), and estimated time of arrival, enabling proactive activation of operating rooms, ICU beds, and specialist teams (Saadatmand et al., 2023). Simulation studies by Yu et al. (2018) show that access to an integrated COP significantly improves decision-making accuracy for bed allocation and staff recall by nursing managers compared to traditional information channels.

Table 1: Evolution of Situational Awareness Tools for MCI Resource Logistics

Era/Paradigm	Key Technologies	Data Flow	Advantages	Limitations & Challenges
Traditional (Analog)	Voice radio, paper triage tags, phone calls, whiteboards.	Unidirectional, sequential, slow. Prone to repetition and loss.	Low-tech, robust, familiar to personnel.	Creates information silos; high cognitive load; no audit trail; prone to error and delay.
Digital Transition	Digital radios, simple electronic patient care records (ePCR), standalone hospital bed boards.	Faster but fragmented. Data exists in separate systems (EMS vs. Hospital).	Creates electronic records; improves data storage and some retrieval.	Lack of interoperability; limited real-time sharing; does not create a unified operational picture.
Integrated & Intelligent	RFID/Bluetooth E-Tags, IoT-enabled equipment, GPS, cloud-based integrated dashboards (COP), predictive analytics modules.	Bidirectional, real-time, and synchronized between field and facility.	Creates a single source of truth; enables proactive decision-making; reduces cognitive load.	High cost; cybersecurity vulnerabilities; requires robust governance & training; risk of system failure.

Figure 1. Data-Driven Resource Optimization Framework for Mass Casualty Incidents

Predictive Analytics and Demand Forecasting for Proactive Resource Activation

Moving beyond real-time awareness, the literature reveals a growing interest in using data to anticipate resource needs. Predictive analytics involves applying statistical models and machine learning algorithms to historical and real-time data to forecast future states (Delen, 2020).

Forecasting Patient Influx and Acuity

For hospital nursing leadership, one of the most critical forecasts is the volume, acuity, and resource profile of incoming patients. Models have been developed using variables such as incident type (e.g., explosion vs. chemical release), initial casualty reports from EMS, geographical proximity, and even social media sentiment analysis to predict patient load (Shi et al., 2022). For instance, research by Weisfeldt et al. (2010) demonstrated a model that, within 30 minutes of an MCI declaration, could predict total ED admissions within a 15% error margin, allowing charge nurses to better stage staffing and supplies. Acuity prediction models, often based on initial field vital signs and mechanism of injury transmitted via E-Tags, can help forecast the need for specific resources like operating room time, blood products, or critical care beds (Trucco et al., 2022).

Modeling Resource Consumption and Supply Chain Dynamics

Predictive analytics also extends to logistics. Discrete-event simulation models are frequently used to simulate patient flow through a hospital system during a surge, identifying potential bottlenecks in imaging, surgery, or ICU admission (Na & Banerjee, 2019). These models can answer "what-if" scenarios for nursing commanders: e.g., if 40 casualties arrive in 60 minutes, how many nursing FTEs are needed in the ED, and when will the ICU capacity be exhausted? Furthermore, predictive models linked to hospital supply chain databases can forecast the depletion rates of key consumables (e.g., chest tubes, tourniquets, specific antibiotics) based on predicted injury patterns, triggering automated alerts to materials management for just-in-time resupply or activation of regional stockpiles (Golan et al., 2020). The governance of the data feeding these models—ensuring its quality, relevance, and timeliness—is repeatedly noted as a fundamental prerequisite for their reliability (Paramita, 2023).

Decision-Support Systems at the EMS-Nursing Command Interface

Data and predictions are only valuable if they are synthesized into actionable intelligence for decision-makers (Table 2). Decision-support systems (DSS) are interactive, computer-based systems designed to help commanders utilize data and models to solve unstructured problems (Bertl et al., 2022).

Supporting EMS Command

For EMS incident commanders, DSS often focuses on dynamic resource redeployment. These systems can process real-time data on ambulance locations, crew competencies, hospital statuses, and traffic conditions to recommend optimal transport destinations ("load-balancing") and the repositioning of idle units to areas of anticipated need (Hajiali et al., 2022; Van Barneveld et al., 2018). This moves beyond simple "closest hospital" directives to a systems-approach that prevents the overwhelming of individual facilities—a key concern for receiving nursing staff (Veenema et al., 2018).

Empowering Nursing Leadership

Within the hospital, nursing-focused DSS are designed to support surge capacity activation decisions. Tiered surge plans (conventional, contingency, crisis) are often protocol-driven, but DSS can provide the data-driven trigger by continuously monitoring key metrics: ED occupancy, ICU ventilator usage, staff-to-patient ratios, and operating room availability (Hick et al., 2022). A DSS can alert the nursing director when thresholds are breached, recommend specific actions (e.g., "Activate Phase 2 Surge: Cancel elective surgeries, open PACU for ICU overflow"), and even automate notifications to off-duty staff with specific skill sets (e.g., trauma nurses, OR nurses) via integrated messaging systems (Saadatmand et al., 2023). Furthermore, staff skill-matching algorithms are an emerging area, where a DSS cross-references incoming patient acuity profiles (from EMS data) with a database of staff competencies and locations to suggest optimal assignment of nurses, thereby maximizing the use of specialized skills under crisis conditions (Fernald et al., 2021).

Table 2: Core Functions of Decision-Support Systems for EMS and Nursing Command in MCIs

Decision-Support Function	Primary User	Data Inputs Required	Typical Output/Recommendation	Governance Consideration
Load-Balancing & Transport Optimization	EMS Incident Commander	Real-time hospital capacities (ED, OR, ICU), ambulance GPS/location, patient acuity from E-Tags, traffic data.	Recommended destination hospital for each ambulance to equitably distribute patient load.	Data-sharing agreements with hospitals; real-time accuracy of capacity data.
Surge Capacity Activation Trigger	Hospital Incident Commander / Nursing Director	Real-time hospital metrics (ED occupancy, ICU bed use, ventilator count, staff present), predictive patient influx models.	Alert and recommendation to escalate to next surge phase (e.g., "Activate Contingency Capacity Plan").	Clear, pre-defined data thresholds; authority to trigger based on system data.
Proactive Staff Recall & Allocation	Nursing Supervisor / Unit Manager	Predicted patient volume & acuity, staff competency database, staff contact & location data.	List of specific staff to recall; suggested nurse-patient assignments based on skill mix.	Privacy and labor agreement compliance for staff data; accuracy of competency records.
Critical Resource Tracking & Replenishment	Logistics Chief / Nurse in Charge of Supplies	IoT data from equipment (ventilators, infusion pumps), inventory consumption rates from supply rooms, and predictive models.	Alerts for low stock of critical items; recommendations for intra-facility equipment transfer.	Standardized naming/ID for all assets; secure IoT network governance.

Data Governance for Crisis Logistics

The sophisticated systems described above are built on a foundation of data. The literature consistently identifies poor data governance as a primary barrier to their effective implementation (Paramita, 2023). Data governance in the context of MCI logistics refers to the policies, standards, and processes that ensure logistical data is available, accurate, secure, interoperable, and used ethically across organizational boundaries during a crisis (Khatri & Brown, 2010). Figure 2 depicts the foundational pillars of data governance required to support effective decision-support systems during mass casualty incidents.

Figure 2. Data Governance Pillars Supporting Decision-Support Systems in Emergency Medical Services

Ensuring Data Quality and Interoperability

In the heat of an MCI, data is often entered hastily, from multiple devices, by different agencies using different standards. Data quality—its accuracy, completeness, timeliness, and consistency—is therefore paramount. Governance must establish pre-defined data entry standards (e.g., mandatory fields in E-Tags), validation rules, and clear accountability for data stewardship at the point of capture (e.g., the paramedic tagging a patient) (McDonald et al., 2022). Interoperability—the ability of systems to exchange and use information—is perhaps the most cited technical challenge. The lack of universal data standards (akin to clinical HL7 or FHIR standards for logistical data) means EMS software often cannot "talk" to hospital dashboards without costly, brittle interfaces (Nadj et al., 2020). Governance must drive the adoption of common data models and exchange protocols for key logistical elements like bed status, resource availability, and patient tracking (Hughes et al., 2022).

Balancing Security, Privacy, and Timely Access

MCIs create a tension between the need for rapid, broad data sharing and the imperatives of cybersecurity and patient privacy. A governance framework must define role-based access controls for crisis systems, ensuring that a nurse manager can see relevant EMS data without exposing the entire hospital network (Elmhadhbi et al., 2021). It must also address the privacy of patient data shared for logistical purposes, often relying on the public health emergency or "minimum necessary" provisions of regulations like HIPAA, but requiring clear, pre-established protocols (Cohen & Mello, 2018). Furthermore, governance plans must include cybersecurity incident response protocols that are integrated with the overall MCI response plan, ensuring that a ransomware attack on a hospital's network does not cripple its surge capacity during a concurrent disaster (Jalali et al., 2018).

Establishing Clear Authority and Ethical Frameworks

Data governance is also an exercise in authority. Who has the right to declare that hospital capacity data is now shared on a regional dashboard? Who can request real-time EMS positioning data? Clear data-sharing agreements that are ratified in peacetime between EMS agencies, hospitals, and public health authorities are essential to avoid legal and bureaucratic paralysis during a crisis (Lennquist, 2012). Finally, an often-overlooked aspect is ethical data governance. Predictive models or DSS recommendations that guide resource allocation in crisis standards of care (e.g., ventilator triage) must be transparent, auditable, and based on ethically defensible algorithms to maintain public trust and ensure fairness (Leider et al., 2017).

Discussion

This narrative review synthesizes a rapidly evolving field that sits at the intersection of disaster medicine, health informatics, operations research, and data science. The trajectory is clear: the future of MCI resource logistics is data-driven, moving from reactive, experience-heavy command to proactive, intelligence-led management. The technological components—real-time tracking, integrated dashboards, predictive models, and intelligent DSS—are in various stages of development and testing, often showing promise in simulation but facing significant real-world implementation hurdles (Hugelius et al., 2020; Saadatmand et al., 2023).

The most salient finding of this synthesis is that technology alone is insufficient. The "softer" aspects of governance, interoperability, human factors, and ethical frameworks are the true determinants of success. A state-of-the-art dashboard is useless if hospital bed data is not updated in real-time due to a lack of nursing workflow integration or if paramedics are not trained to use E-Tags effectively under duress. The literature repeatedly highlights failures at the human-technology interface: systems that are too complex for high-stress use, alerts that contribute to alarm fatigue for nursing commanders, or a lack of trust in algorithmic recommendations by seasoned personnel (Endsley, 2020; Castoldi et al., 2022).

Therefore, future development must adopt a human-centered design approach, co-creating systems with frontline EMS providers and nursing leaders. Furthermore, investment must shift from purely technological procurement to the development of the governance infrastructure: standardized data agreements, interoperable frameworks, continuous training regimes, and ethical guidelines. Research should move beyond proof-of-concept simulations to longitudinal studies of real-world implementation, measuring outcomes not just in terms of system usage, but in improved patient outcomes (e.g., reduced time to definitive care, lower mortality), more efficient resource utilization, and reduced provider burnout during MCIs.

Conclusion

Optimizing the allocation of scarce personnel, equipment, and space during a mass casualty incident is a complex, high-stakes endeavor that defines the line between systemic failure and resilience. This review demonstrates that achieving this optimization is increasingly dependent on the seamless flow and intelligent analysis of logistical data between the field operations of EMS and the institutional command of nursing leadership within disaster centers. While technological advancements in situational awareness dashboards, predictive analytics, and decision-support systems offer transformative potential, their efficacy is wholly contingent upon the establishment of robust, pre-planned data governance frameworks. These frameworks must ensure data quality, enforce interoperability, balance security with accessibility, and provide clear ethical guidance.

The journey towards a truly integrated, data-informed MCI response system is a multidisciplinary undertaking. It requires the collaborative commitment of emergency physicians, nurses, paramedics, informaticians, data scientists, cybersecurity experts, and health administrators. By prioritizing not only the tools but also the governance, training, and ethical foundations that make them trustworthy, healthcare systems can evolve from merely reacting to disasters to proactively managing them, thereby safeguarding both patient lives and the well-being of the providers tasked with their care in the most challenging of circumstances.

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