Exploring the Dimensions and Components of Pharmaceutical and Medical Equipment Supply Chain Preparedness in Disasters: A Qualitative Study

Abstract

Aims:

This study aimed to identify and elucidate the dimensions of preparedness of the pharmaceutical and medical equipment supply chain in disaster settings within the military health system in Iran.

Methods:

A qualitative study using conventional content analysis grounded in a constructivist paradigm was conducted. Purposive sampling with a maximum variation strategy was applied, and 18 senior managers involved in procurement, storage, and distribution processes participated in semi-structured interviews. Data were analyzed concurrently with collection using the five-step approach of Hsieh and Shannon, and findings were organized through framework synthesis.

Findings:

A total of 739 initial codes were extracted and subsequently condensed into 6 main themes, 16 categories, and 45 subcategories. The identified dimensions included needs assessment, selection and stockpiling of pharmaceuticals and equipment, demand forecasting, logistics infrastructure and distribution, inter-sectoral and inter-organizational coordination, and human resource and technological support. Preparedness was found to be a multidimensional and dynamic construct influenced by structural alignment, intelligent forecasting, efficient logistics management, coordinated governance, and the integration of advanced technologies.

Conclusion:

Strengthening supply chain preparedness in disasters requires a comprehensive approach encompassing workforce capacity building, data-driven forecasting systems, structural reform of logistics networks, and enhanced inter-organizational coordination. Weakness in any of these dimensions may result in significant disruptions in the availability of essential medical supplies during crises.

Keywords: Disaster Planning, Supply Chain Management, Drug Distribution Systems, Strategic Stockpile, Logistics.

Introduction

In today's world, the pharmaceutical and medical equipment supply chain is recognized as one of the fundamental pillars of health systems. The efficiency and effectiveness of this supply chain are profoundly affected during crises, including natural disasters, pandemics, and humanitarian emergencies. Under such circumstances, any deficiency or disruption in procurement, storage, and distribution processes of medicines and medical equipment can lead to serious and irreversible consequences. Disasters create significant challenges in maintaining adequate pharmaceutical inventories and ensuring the availability of essential medical equipment, thereby reducing the capacity to respond to health and medical needs. This, in turn, may result in increased mortality and a decline in the quality of healthcare services (1).

The sustainable provision of medicines and medical equipment constitutes one of the core components of health systems during disasters. Previous research has identified weaknesses in coordination and rapid response to shortages, insufficient preparedness, and the lack of appropriate infrastructure for supplying essential items as major challenges faced by health systems in disaster settings (2). For instance, during the COVID-19 pandemic, many countries encountered serious difficulties in the procurement and distribution of pharmaceuticals and medical supplies. This crisis revealed that, despite prior projections and planning efforts, numerous systems were unable to effectively meet healthcare demands (3).

Given these challenges, assessing and analyzing the preparedness of pharmaceutical and medical equipment supply chains—particularly during disaster—has become a primary concern for health researchers and managers. As disaster conditions directly influence the efficiency and resilience of health systems, preparedness of the pharmaceutical supply chain for disaster management is of critical importance. Previous studies have predominantly focused on macro-level resilience assessments or quantitative analyses of supply systems; however, more detailed qualitative perspectives on the dimensions of supply chain preparedness—especially at the organizational and operational levels within the Islamic Republic of Iran Army—have not yet been comprehensively and systematically examined (2, 4).

Numerous studies have demonstrated that, in order to enhance disaster response, the various components and dimensions of supply chain preparedness must be identified and conceptualized within the context of different types of disasters. These components broadly encompass stakeholder engagement, the role of policymaking, preventive planning, information technology, and interorganizational coordination (5, 6). Furthermore, evidence indicates that robust information systems, coordinated communication infrastructures, and effective resource management are critical factors in reducing procurement time and costs during crises. However, in many instances, these systems experience disruptions and performance decline, thereby underscoring the need for more precise and targeted management approaches in this domain (7, 8). Given the critical importance of disaster management and the necessity of developing a comprehensive and practical framework for analyzing the preparedness of pharmaceutical and medical equipment supply chains (4), the present study aims to examine and analyze the various dimensions of supply chain preparedness during disasters.

The objective of this research is to identify and elucidate the key components of preparedness within pharmaceutical and medical equipment supply chains using a qualitative approach. In particular, this study seeks to analyze the experiences of managers and experts within the health system of the Islamic Republic of Iran Army in order to identify and categorize the dimensions and influencing factors affecting supply chain performance under crisis conditions. The findings of this study may assist policymakers and planners within the Health Deputy of the Islamic Republic of Iran Army in recognizing existing strengths and weaknesses in supply chain preparedness and in formulating optimal disaster response strategies.

As health Hazard — particularly pandemics and natural disasters—are increasing in frequency and severity, a comprehensive understanding of the structure and components of pharmaceutical and medical equipment supply chain preparedness is of paramount importance. In light of the global challenges that emerge during health hazards, the capacity of national armed forces to maintain a stable and resilient supply chain can play a vital role in mitigating adverse impacts and safeguarding public health. Accordingly, this study aims to provide an in-depth and comprehensive analysis of the components and dimensions of supply chain preparedness in the face of disasters and to offer a new perspective in this field.

Information & Methods:

This study employed a qualitative design using conventional content analysis with an exploratory–descriptive approach, grounded in the constructivist paradigm. The selection of this approach was based on the assumption that preparedness of the supply chain in disasters is not an objective and static phenomenon; rather, it is a multifaceted, dynamic reality constructed through complex interactions among stakeholders, organizational structures, and environmental conditions.

The researchers' approach was centered on qualitative conceptualization and causal explanation. Therefore, to enable an in-depth qualitative analysis of the interviews obtained and to examine, describe, explain, and interpret underlying causes the framework synthesis method was applied to transform the content analysis findings into an operational model.

The study population consisted of senior managers and crisis management authorities involved at all levels of the procurement, storage, and distribution processes of pharmaceuticals and medical equipment within the health system of the Islamic Republic of Iran Army. This scope encompassed: (1) the headquarters and policy-making level, (2) the operational and logistics level, and (3) the service delivery level.

In this study, purposive sampling with a maximum variation strategy was employed. The inclusion criteria comprised: (1) professional experience—a minimum of five years of managerial or executive experience related to the pharmaceutical supply chain, medical equipment supply, or crisis management; (2) lived crisis experience—direct experience of participation in or management of at least one major crisis (e.g., earthquakes, the COVID-19 pandemic, or war); (3) organizational position—holding a command-level position within the health system of the Islamic Republic of Iran Army; and (4) willingness to participate—providing informed consent and demonstrating the ability to articulate experiences and convey complex concepts.

The exclusion criteria included: (1) withdrawal from participation—unwillingness to continue cooperation at any stage of the study (during or after the interview); (2) incomplete data—inability to complete the interview due to reasons such as time constraints, illness, or communication disruption, resulting in non-analyzable data; (3) insufficient informational richness—the researcher's determination that, despite relevant work history, the participant lacked adequate experience or knowledge regarding crisis and disaster conditions (i.e., data redundancy or "information saturation" at the individual level); and (4) refusal of audio recording—lack of consent to audio-record the interview.

A total of 18 experts participated in the study. Interviews were conducted until data saturation was achieved. Although repetition in the data was observed by the fifteenth interview, the researchers conducted three additional interviews to ensure comprehensive coverage of all sub-dimensions. The data collection process was concluded after the eighteenth participant.

Data Collection and Analysis

The primary data collection tool was in-depth semi-structured interviews. A total of 18 face-to-face semi-structured interviews were conducted between February 2025 and September 2025. Each interview lasted approximately 45 to 60 minutes and was held in a quiet and private setting at the participants' workplace to ensure comfort and a sense of security in sharing their experiences.

In addition to audio recording, field notes were taken concurrently to document non-verbal cues, emotional reactions, and key points requiring further probing in subsequent questions. The interview guide was developed based on a review of the literature and the objectives of the study. Interviews began with broad, open-ended questions and were progressively directed toward more exploratory and focused inquiries.

Examples of interview questions included:

- **Main question:** "Please describe your experience with the process of pharmaceutical procurement and distribution during the crises you have managed."
- **Exploratory question:** "You mentioned challenges in needs assessment; specifically, what structural or informational barriers led to discrepancies between your estimates and the actual needs?"
- **Focused question:** "How is coordination between your organization and parallel institutions (e.g., the Red Crescent) established during the initial moments of a crisis?"

Data analysis was conducted concurrently with data collection. This iterative approach enabled the researchers to refine and deepen subsequent interview questions based on emerging concepts. Conventional content analysis was performed following the five-step method proposed by Hsieh and Shannon (2005), incorporating the unit-of-analysis concepts described by Graneheim and Lundman (2004). In this approach, categories and codes were derived directly from the raw data, and the researchers deliberately avoided imposing pre-existing theoretical frameworks onto the findings.

The analysis process began with immersion in the data. After each interview, the audio file was transcribed verbatim, and the resulting transcript was read twice by the researchers to achieve a comprehensive understanding. Initial coding was then performed by identifying meaning units (words, sentences, or paragraphs containing related messages). These units were condensed and subsequently labeled with open codes.

For example, the statement:

"We did not know how much IV fluid remained in our field hospital inventory because the system was down"

was condensed into the meaning unit:

"Lack of real-time inventory awareness due to system failure"

and assigned the initial code:

"Deficiency in inventory tracking systems."

Data management and analysis were conducted using MAXQDA software (version 2020).

Findings:

A total of 18 senior managers and crisis management authorities from the health system of the Islamic Republic of Iran Army participated in this study. Their demographic characteristics are presented in Figure1.

Figure1. Demographic Characteristics of the Participants (n = 18)

Interview No.	Gender	Age (years)	Education Level	Work Experience (years)

p1	Male	45	PhD	20
p2	Male	38	Master's degree	15
p3	Male	50	PhD	25
p4	Female	42	Master's degree	18
p5	Male	55	PhD	30
p6	Male	40	PhD	12
p7	Male	48	PhD	22
p8	Male	35	Master's degree	10
p9	Male	47	PhD	23
p10	Male	44	Master's degree	17
p11	Male	49	PhD	28
p12	Female	39	PhD	14
p13	Male	53	PhD	27
p14	Female	41	Master's degree	16
p15	Male	46	PhD	21
p16	Male	50	Master's degree	20
p17	Male	52	PhD	29
p18	Male	43	PhD	15

An in-depth and rigorous analysis of the data obtained from the 18 expert interviews resulted in the extraction of 739 initial codes. Following iterative processes of reduction and abstraction, these codes were organized into 6 main themes, 16 categories, and 45 subcategories. The final analytical framework derived from the coding and abstraction process is presented in Figure 2. These themes represent the key and critical dimensions of pharmaceutical and medical equipment supply chain preparedness in disaster settings. Each dimension is elaborated in detail below, supported by representative direct quotations and interpretative analysis by the researchers.

Table 2. Final Analytical Framework of Supply Chain Preparedness Dimensions in Disasters

Primary Codes	**Subcategories**	**Categories**	**Theme**
Type of organizational structure	Structural Factors Influencing Supply Chain Needs Assessment	Needs Assessment	Supply Chain Planning and Decision-Making
Exclusion of end users from the decision-making process			
Lack of assessment of market dynamics and supply structure impacts on needs estimation	Operational Factors Influencing Supply Chain Needs Assessment		
Inaccurate evaluation of pharmaceutical stock during crises			
Failure to identify structural barriers to systematic needs assessment			
Absence of alternative strategies for pharmaceutical procurement			
Non-systematic use of needs assessment analytical tools			
Lack of timely field-based assessment			
Failure to utilize lessons learned from disaster management	Knowledge Translation and Capacity Building for Supply Chain Needs Assessment		
Neglect of global knowledge and benchmarking data in crises			
Absence of multi-level and time-bound scenario-based forecasting			
Lack of reference lists for sensitive, strategic, and crisis-specific medicines			
Failure to develop new lists for emerging or unprecedented crises			
Inefficient stockpiling and ordering not based on consumption analysis			

Lack of data-driven analytics for forecasting pharmaceutical needs	Intelligent Management in Supply Chain Needs Assessment		
Neglect of inventory systems in forecasting and management	Intelligent Demand Forecasting Management	Demand Forecasting	
Failure to identify episodic demand patterns using analytical tools			
Absence of integrated software systems			
Failure to revise distribution lists and structural frameworks during crises	Structural Reforms in Demand Forecasting		
Unaddressed structural challenges in medical equipment management			
Inadequate consideration of economic constraints in demand forecasting			
Failure to identify crisis dimensions	Crisis-Oriented Forecasting		
Lack of effective strategies for managing pharmaceutical shortages			
Inefficient pharmaceutical storage management	Management of Pharmaceutical and Equipment Stockpiling	Selection and Stockpiling of Pharmaceuticals /Equipment	Resource Management and Logistics Operations
Storage not aligned with healthcare facility structure			
Storage decisions not based on analytical tools			
Lack of strategic thinking in pharmaceutical resource selection	Management of Pharmaceutical/Equipment Selection		
Weak management of the pharmaceutical selection and procurement chain			
Failure to identify disaster dimensions and define appropriate pharmaceutical baskets	Contingency-Based Management of Pharmaceuticals/Equipmen t		
Absence of structured operational disaster management processes			
Inadequate evaluation of physical infrastructure	Structural Evaluation of Logistics Infrastructure and Distribution	Logistics Infrastructure and Distribution	
Weak pharmaceutical distribution infrastructure			
Lack of structural reform in human resource allocation			
Absence of intelligent infrastructure			
Failure to update data in real time	Functional Evaluation of Logistics Infrastructure and Distribution		
Weak evaluation of inventory management system performance			
Inefficient operational management of equipment supply and distribution			
Poor operational management of the pharmaceutical distribution chain during crises			
Absence of formal internal processes for declaring pharmaceutical and equipment needs	Intra-organizational Coordination in Pharmaceutical and Equipment Supply Chain	Inter-sectoral and Inter-organizational Coordination	Coordination and System Integration
Weak internal management of pharmaceutical supply			
Lack of control and coordination in inter-organizational decision-making and policymaking during crises	Inter-organizational Coordination in Pharmaceutical and Equipment Supply Chain		
Weak human resource management	Human Resource Support		Enabling Capacities and
Insufficient human resource training			

Failure to utilize artificial intelligence and analytical software for forecasting and resource management	Technology Support	Human Resource and Technology Support	Support Systems
Inadequate communication infrastructure			

Category 1: Needs Assessment

The cornerstone of any successful logistics operation is an accurate understanding of needs. Data analysis revealed that in crisis situations, needs assessment is not a linear process; rather, it is shaped by a complex interaction among organizational structures, operational variables, and the tacit knowledge of managers. This construct comprises three primary subcategories:

1-1) Structural Factors Influencing Needs Assessment

Participants emphasized that the *physical and organizational capacity* of a healthcare facility significantly shapes its demand pattern. In particular, one participant (P4) stated: "We cannot apply the same ordering pattern used for a university hospital to a 50-bed field hospital; however, guidelines are sometimes communicated uniformly, which leads to either overstocking or shortages." In this regard, factors such as *bed capacity*, *specialized service structure* (e.g., burn or orthopedic units), and *service utilization rate* (Bed Occupancy Rate) were identified as key variables in determining pharmaceutical needs.

Moreover, contrary to the common assumption that pharmacists are the sole decision-makers in medication supply, the findings indicated that *physicians' decisions* and the clinical staff—being the end users—act as the primary drivers of demand. One interviewee (P8) noted: "If, during a crisis, physicians do not adhere to standard treatment protocols or, under psychological pressure, submit unnecessary requests, the supply chain becomes disrupted."

This finding highlights that needs assessment is not merely a technical calculation based on inventory data, but rather a structurally embedded and behaviorally influenced process shaped by clinical practice patterns and organizational characteristics.

1-2) Operational Factors Influencing Needs Assessment

This subcategory refers to the operational dynamics that emerge during crises. One of the key findings was the impact of *pharmaceutical market turbulence* on needs assessment. Rumors of drug shortages during emergencies often prompt healthcare facilities to order quantities exceeding actual demand—a phenomenon commonly referred to as the *bullwhip effect*. As one participant (P14) stated: "Analyzing market conditions and assessing transparency in pharmaceutical stock levels are among the most critical needs."

In addition, the absence of a *strategic resource plan* and weaknesses in *financial resource allocation mechanisms* may result in needs assessment being driven more by available budget than by patients' actual clinical requirements.

During the initial moments of a crisis—the so-called *Golden Time*—software systems are frequently inefficient or disrupted. Consequently, the capacity for *field-based assessment* and the physical presence of experts in affected areas for rapid needs estimation (Rapid Assessment) were identified as vital factors. One participant (P6) remarked: "In the early hours of a crisis, systems are usually ineffective, and field assessment—especially in the initial stages—is essential."

These findings underscore that operational volatility, financial governance, and real-time situational awareness critically shape the accuracy of needs estimation in disaster settings.

1-3) Knowledge Translation and Capacity Building

The application of knowledge to enhance the precision of needs assessment emerged as a central theme in this study. Many managers indicated that crises often represent a repetition of previous mistakes. In this context, *managerial experience transfer* and *inter-organizational learning* were identified as mechanisms to reduce estimation errors. As one interviewee (P9) noted: "Transferring the experience of managing the Golestan floods to Khuzestan could reduce estimation errors by up to 50 percent."

Furthermore, the utilization of *global data* and World Health Organization (WHO) protocols for forecasting required items in specific crises, including bioterrorism scenarios, was considered essential. One participant (P3) emphasized: "Using WHO protocols to forecast pharmaceutical needs in crises helps us take more timely and accurate actions."

Moreover, needs forecasting should be *scenario-based*. In other words, for crises such as earthquakes, war, or pandemics, predefined *pharmaceutical packages* should be developed to separately address the needs of chronic patients and those acutely affected by the disaster.

Collectively, these findings demonstrate that effective needs assessment in disasters requires not only structural and operational readiness but also systematic knowledge translation, scenario planning, and institutional memory integration.

Category 2: Selection and Stockpiling of Pharmaceuticals and Medical Equipment

This construct addresses inventory strategies and stockpiling management. The findings revealed a major paradox in this domain: *the legal obligation to maintain reserves versus operational constraints limiting implementation*.

2-1) Management of Pharmaceutical and Equipment Stockpiling

In the process of managing pharmaceutical and medical equipment stockpiling, participants emphasized that infrastructural limitations—such as the *lack of standard warehouses* and *insufficient cold storage capacity*—pose significant barriers to achieving strategic reserves. One interviewee (P15) stated: "We are obligated to maintain reserves, yet we do not even have sufficient space for routine hospital medications—let alone emergency stockpiles."

This statement highlights the impact of physical storage constraints within healthcare facilities.

Furthermore, stockpiling processes must be tailored to the *structure and characteristics of each healthcare facility*. One participant (P13) explained: "In some healthcare centers, stockpiling is mandatory due to the type of organization and their specific needs."

These findings underscore the importance of aligning stockpiling policies with organizational structure, available infrastructure, and governmental regulations. In this context, the use of *ABC analysis* was proposed as a strategic approach to identify the 20% of items that account for 80% of critical value during crises.

2-2) Management of Pharmaceutical and Equipment Selection

The selection of pharmaceuticals for stockpiling should not be arbitrary; rather, it must be guided by the *Official National Drug List of Iran*, continuous monitoring of the production market, and regular updating of the pharmaceutical needs profile. One participant (P12) stated: "A strategic approach to drug selection means considering expiration dates and the possibility of rotation of stockpiled medicines within the routine consumption system to prevent waste."

This perspective highlights the necessity of a systematic and strategic selection process that simultaneously ensures preparedness and minimizes pharmaceutical wastage.

2-3) Contingency-Based Management

In disaster management, the first step is determining the *type of pharmaceuticals appropriate to the specific crisis*. The nature of the crisis directly influences medication selection, particularly when the *pattern of disease and injury* shapes demand. One interviewee (P7) explained: "In earthquakes, there is a need for antibiotics, IV fluids, and orthopedic supplies, whereas in chemical attacks, antidotes are required."

This statement clearly demonstrates that pharmaceutical selection must be crisis-specific and scenario-driven.

In addition, *prioritization of medicines* should be carefully aligned with the type and scale of the emergency to ensure optimal resource allocation. Accordingly, designing operational crisis management processes and establishing specialized response teams are crucial for rapid assessment and effective decision-making. As one participant (P10) noted: "Specialized teams must act quickly and effectively in crisis situations to ensure the timely provision of pharmaceutical needs."

Moreover, zoning affected areas into six or seven operational blocks and continuously monitoring them through designated teams facilitates better crisis control. Systematic documentation of pharmaceutical needs and related challenges using structured reporting forms, followed by timely data processing to support prompt distribution, was also identified as an essential operational practice.

Category 3: Demand Forecasting

The central message of this category is the transition from traditional forecasting—based on average historical consumption—to intelligent, crisis-responsive forecasting models.

3-1) Intelligent Management of Demand Forecasting

The findings emphasized the necessity of advanced analytical tools to *differentiate episodic demand patterns* and identify *surge demand*. One participant (P1) stated: "Traditional inventory systems are unable to distinguish routine consumption from crisis-related consumption and therefore generate misleading data."

This observation highlights the need for intelligent software systems and predictive algorithms capable of improving demand forecasting during emergencies.

Moreover, participants underscored the importance of designing software platforms that function in a *predictive* rather than merely *descriptive* manner, particularly in modeling budgetary allocation and supply capacity. As one interviewee (P6) explained: "We need a system that can model demands and supplies predictively—not just descriptively."

These findings indicate that data-driven, algorithm-based forecasting systems are critical for enhancing responsiveness and minimizing distortion in crisis conditions.

3-2) Structural Reforms in Forecasting

One of the most significant issues identified was the need to *restructure the pharmaceutical distribution network*. The current distribution framework is designed for routine conditions; however, during crises—when demand surges in a specific geographic hotspot—structural flexibility becomes essential. As one participant (P2) noted: "During crises, the distribution network must have the capability for rapid flexibility and rerouting."

Such reforms include structural redesign of the distribution network and revision of allocation lists, both of which can substantially reduce lead time for pharmaceutical supply during emergencies.

3-3) Crisis-Oriented Forecasting

Pharmaceutical demand forecasting in disaster settings must be based on the *size and vulnerability of the affected population*, *severity of the crisis*, and *probabilistic scenario modeling*. Decisions must be updated in real time to ensure maximum responsiveness. One participant (P5) explained: "In crises, forecasting must be accurate and up-to-date so that we can respond quickly to actual needs."

In this context, maintaining *multi-month pharmaceutical reserves* was proposed as a strategy to mitigate uncertainty in forecasting. As another interviewee (P7) stated: "Long-term stockpiling is one way to cope with inaccurate forecasts and unpredictable conditions."

Collectively, this category demonstrates that effective demand forecasting in disasters requires technological innovation, structural adaptability, real-time decision-making capacity, and strategic buffering against uncertainty.

Category 4: Logistics Infrastructure and Distribution

4-1) Structural Evaluation of Logistics Infrastructure and Pharmaceutical and Equipment Distribution

Logistics constitutes the backbone of relief operations. Without efficient distribution, even fully stocked warehouses become ineffective. The evaluation of logistics infrastructure and the distribution of pharmaceuticals and medical equipment was identified as a core pillar of crisis management.

One participant (P4) emphasized: "Establishing an appropriate structure for the distribution of medicines and equipment during crises is critically important, as even the smallest flaw can disrupt the entire procurement and distribution process."

This evaluation encompassed assessment of the physical infrastructure, including the availability of standard warehouses and adequate cold storage facilities for safeguarding vital medicines under emergency conditions.

Additionally, pharmaceutical distribution challenges in certain rural areas and small cities—particularly during crises—were identified as a serious concern. One interviewee (P7) stated: "The slow distribution of medicines in these areas prevents the rapid fulfillment of pharmaceutical needs during crises."

Accordingly, the need to revise the pharmaceutical distribution system and implement structural reforms in human resource allocation was strongly emphasized. Furthermore, the development of intelligent, real-time, and error-minimizing distribution management systems was proposed as a fundamental strategy for strengthening logistics performance in emergency settings.

4-2) Functional Evaluation of Logistics Infrastructure and Distribution Systems

From a functional perspective, continuous data updating and access to accurate, real-time information were identified as essential requirements. One participant (P6) explained: "Access to accurate and up-to-date data—not only in crises but also in routine conditions—enables us to plan according to actual needs for medicines and equipment."

Such data are vital for identifying urgent demands and ensuring optimal resource allocation during emergencies.

Performance evaluation of warehousing systems was also considered crucial. One interviewee (P10) stated: "Inventory systems must be capable of controlling stock levels during crises; otherwise, we will face either overstocking or shortages."

This finding underscores the importance of robust inventory control processes and periodic review of accounting and tracking systems in evaluating distribution performance.
Regarding operational management within the pharmaceutical distribution chain during crises, one participant (P2) remarked: "In crises, attention to the actual capacities of regions and effective financial support for the supply chain can significantly improve the distribution of medicines and medical equipment."
This statement highlights the importance of resource governance and inter-sectoral coordination during emergencies.
Moreover, adherence to established crisis distribution guidelines and avoidance of arbitrary or uncoordinated distribution were identified as critical measures. As one participant (P10) emphasized: "In emergency situations, any arbitrary distribution can exacerbate the crisis; therefore, strict adherence to guidelines is essential."
Collectively, this category demonstrates that both structural robustness and functional efficiency of logistics systems are indispensable for ensuring equitable, timely, and controlled distribution of pharmaceuticals and medical equipment in disaster settings.
Category 5: Inter-sectoral and Inter-organizational Coordination
Lack of coordination was identified as the "Achilles' heel" of crisis management in Iran. The data revealed the presence of multiple managerial "silos," which undermine coherent and unified responses.
5-1) Intra-organizational Coordination
Within hospitals and universities, informal networks and personal relationships sometimes replace formal needs-reporting procedures. One participant (P5) explained: "At times, formal processes are completely bypassed, and decisions are made based on personal relationships."
This observation highlights the necessity of *formalizing operational processes*, particularly regarding the declaration of needs and allocation of scarce pharmaceuticals. Another participant (P7) stated: "The design of a formal, protocol-based process for declaring needs and optimally allocating scarce medicines must be predefined so that, during crises, managerial deviations do not occur."
These findings suggest that institutional resilience depends not only on resources but also on procedural clarity, governance integrity, and adherence to standardized protocols.
5-2) Inter-organizational Coordination
A major challenge in inter-organizational coordination was the management of conflicts and parallel operations. The multiplicity of actors—including the Ministry of Health, the Red Crescent, the Armed Forces, Civil Defense authorities, provincial administrations, and charitable organizations—often leads to duplication of efforts and inefficient resource utilization. One interviewee (P4) stated: "The multiplicity of actors in crises leads to unclear division of responsibilities and ineffective distribution of available resources."
Accordingly, clearly defining the scope of intervention and responsibilities of each organization was identified as a key solution. As one participant (P8) noted: "In the first phase of a crisis, it must be clearly defined who is responsible for procurement, and in subsequent phases, to whom this responsibility is transferred. Clarifying these roles, alongside reducing conflicts, can significantly improve inter-organizational coordination."
Furthermore, inter-organizational engagement should shift from a competitive model toward a synergistic approach, in which each entity fulfills its role collaboratively and within a unified operational framework.
Collectively, this category underscores that effective pharmaceutical supply chain preparedness in disasters requires governance integration, clear delineation of roles, reduction of parallelism, and the institutionalization of cooperative mechanisms across sectors.
Category 6: Support Systems — Human Resources and Technology
This category highlights the enabling functions that sustain and reinforce the pharmaceutical supply chain during crises, particularly human resource capacity and technological infrastructure.
6-1) Human Resource Support
Human resource support was identified as a critical determinant of successful crisis management. One participant (P5) emphasized: "Support and pharmaceutical staff during crises must have a 'military mindset'—disciplined, fast, and resilient."
Such a mindset is essential in high-pressure environments where rapid response and operational readiness are indispensable.

Participants underscored the importance of pre-crisis planning for *specialized skills training* and the development of *rapid response personnel*. As one interviewee (P7) explained: "During crises, burnout occurs quickly; therefore, protocols for workforce compensation and shift replacement must be in place."

These findings indicate that workforce sustainability, psychological resilience, and structured contingency staffing plans are fundamental to maintaining continuity of pharmaceutical services in emergencies.

6-2) Technological Support

In the domain of technological support, the application of emerging technologies—such as Artificial Intelligence (AI) and big data analytics—was identified as a strategic tool for analyzing consumption patterns and forecasting shortages. One participant (P9) stated: "Using artificial intelligence to predict shortages before they occur can significantly improve crisis management."

Additionally, *data integration*—including the use of electronic prescribing data—and the establishment of unified, formal information systems were recognized as key mechanisms for effective resource management. As one participant (P8) noted: "Technology can bridge the gap between 'actual need' and 'available inventory' by providing accurate data."

These findings emphasize that digital transformation and intelligent data systems are not merely supportive tools but strategic enablers of resilience, transparency, and responsiveness within the pharmaceutical supply chain during disasters.

Discussion

This study explored the dimensions and components of preparedness within the pharmaceutical and medical equipment supply chain in crisis settings. During emergencies, the performance of pharmaceutical and medical supply systems represents a fundamental pillar for effective disaster management and the protection of public health .

The findings indicate that preparedness of pharmaceutical and medical equipment supply chains in disasters is shaped by six interrelated dimensions: needs assessment, selection and stockpiling of medicines and equipment, demand forecasting, logistics infrastructure and distribution, inter-organizational coordination, and human resource and technological support. Importantly, the results suggest that these dimensions operate as an integrated system rather than independent components; therefore, deficiencies in any single dimension may trigger cascading failures and secondary crises, such as critical shortages of medicines and medical supplies, particularly in large-scale and unexpected emergencies.

The findings of this study are consistent with prior research, including studies by Hamdi et al. and Bastani et al., which emphasize the critical importance of strengthening health system preparedness and enhancing resource supply mechanisms in crisis situations (9, 10). However, the present study extends this body of knowledge by demonstrating that structural and procedural challenges—particularly inter-organizational fragmentation and deficiencies in accurate demand forecasting—act as central mechanisms that undermine supply chain efficiency during emergencies. These findings highlight the pivotal role of structural coherence and data-driven planning in improving the performance of healthcare supply chains.

Supporting this interpretation, existing literature highlights that the level of pre-crisis preparedness and the system's adaptive capacity are fundamental to supply chain resilience in the face of disruptions. Ivanov et al. showed that the viability and survivability of supply networks under large-scale disruptions depend heavily on prior preparedness and the ability to dynamically respond to environmental changes (11). Similarly, Paul et al., in their analysis of the COVID-19 pandemic, argue that the crisis exposed significant structural weaknesses in health systems—particularly in the supply and distribution of critical resources—and underscored the urgent need to reconsider system integration and preparedness strategies (12).

Furthermore, the present findings regarding structural and procedural challenges are aligned with recent empirical evidence. Chandra et al. demonstrated that the sudden surge in demand for medical equipment during the COVID-19 pandemic, combined with insufficient coordination among stakeholders, imposed substantial pressure on supply chains and disrupted access to essential resources. Their study further emphasizes that the adoption of advanced technologies and Industry 4.0 tools can enhance healthcare supply chain performance by improving demand forecasting accuracy, increasing information transparency, and strengthening inter-organizational coordination (13). Taken together, these findings suggest that preparedness is not solely a function of resource availability, but rather depends on the systemic alignment of structures, processes, and information flows.

The present study also demonstrates that needs assessment in crisis situations is a complex, dynamic, and non-linear process shaped by interactions among organizational structures, operational variables, and the tacit knowledge of decision-makers. These findings indicate that needs assessment cannot be conducted solely based on fixed and predefined indicators; instead, it must be contextualized according to the actual capacities, operational conditions, and local characteristics of each healthcare facility. In this regard, variations in physical and organizational capacity across hospitals and healthcare centers necessitate the use of differentiated approaches and tailored allocation strategies. This finding is consistent with Soltani et al. (14), who emphasized the importance of aligning resource allocation strategies with the specific characteristics of each healthcare facility.

These results are further supported by existing evidence in the literature. For instance, Bravata et al. (15) demonstrate that hospital capacity assessment during crises such as COVID-19 requires dynamic and multi-level models capable of capturing variations in resources, infrastructure, and patient load across facilities. Similarly, Taccone et al. (16) argue that resource allocation decisions in emergency settings must be aligned with the actual capacities and operational constraints of individual healthcare centers, as uniform strategies may lead to inefficiencies and suboptimal outcomes.

Moreover, the findings of this study highlight the significant role of behavioral and informational factors in shaping supply chain dynamics during crises. Specifically, rumors regarding drug shortages and pharmaceutical market fluctuations can lead to overordering behaviors, thereby exacerbating instability within the supply chain—a phenomenon known as the "bullwhip effect." This issue has also been reported by Moreno et al. (17), who emphasize the importance of transparency in inventory management and strategic resource planning. In addition, Zheng et al. (18) show that lack of information transparency and emotionally driven responses under uncertainty can amplify demand fluctuations, while Paul et al. (19) argue that panic-driven behaviors and incomplete information during pandemics can result in severe imbalances between supply and demand.

In contrast, some studies, such as Subramanian (20), emphasize the role of software-based systems and predictive models in managing demand and resource allocation. However, the findings of the present study suggest that, particularly in the early stages of a crisis, field-based assessment and situational awareness may be more effective than purely data-driven approaches, especially when initial data are incomplete or highly uncertain. This apparent tension highlights the need for a hybrid approach that integrates field-based assessment, data-driven analytics, and behavioral management strategies in order to enhance the accuracy of needs assessment and optimize resource allocation in crisis settings.

The study also revealed that one of the primary challenges in the selection and stockpiling of pharmaceuticals and medical equipment during crises is the tension between regulatory requirements for maintaining reserves and practical operational constraints. Many healthcare centers face infrastructural limitations, including the lack of standardized warehouses and adequate cold chain storage, which significantly hinder effective stockpiling. These findings are consistent with Guo et al. (21), who reported similar infrastructural barriers affecting pharmaceutical and medical supply reserves in disaster settings.

Moreover, the selection of pharmaceuticals for stockpiling should be continuously aligned with national essential medicines lists, as well as real-time monitoring of production and supply markets, in order to prevent both overstocking and shortages. This finding is supported by Deressa et al. (22), who emphasized the importance of strategic pharmaceutical selection and the use of prioritization tools such as ABC analysis to ensure the availability of critical items during crises.

Importantly, the present study highlights that pharmaceutical selection must be context- and crisis-specific. Different types of emergencies—such as natural disasters (e.g., earthquakes) versus human-made threats (e.g., chemical or nuclear incidents)—generate distinct pharmaceutical and medical needs. Therefore, stockpiling strategies should be tailored to the specific characteristics, risk profiles, and anticipated health consequences of each hazard. This perspective is consistent with Nocci et al. (23), who emphasized the necessity of maintaining targeted pharmaceutical and medical countermeasure reserves for radiological and nuclear emergencies. Their findings suggest that risk-based and threat-specific stockpiling strategies are essential, as reliance solely on general-purpose medicines is insufficient without incorporating specialized countermeasures for specific hazard scenarios.

The present study further demonstrates that transitioning from traditional consumption-based forecasting approaches to intelligent, dynamic, and data-driven forecasting is a fundamental requirement for effective supply chain management in crisis settings. The use of advanced analytical tools—particularly for identifying intermittent demand patterns and predicting sudden surges in demand (surge demand)—can play a critical role in preventing major disruptions in the supply of pharmaceuticals and medical equipment. These findings are consistent with previous studies, including Yang et al. (24) and Subramanian (20), which emphasize the importance of employing advanced forecasting models under conditions of uncertainty.

Supporting this perspective, Ivanov and Dolgui (11) demonstrate that, in the context of large-scale disruptions, analytical and scenario-based models are essential for maintaining supply chain stability. Similarly, Choi (25) highlights that traditional forecasting methods become ineffective during crises such as COVID-19, increasing the need for real-time, data-driven approaches. Furthermore, Kumar et al. (26) show that the adoption of Industry 4.0 technologies and big data analytics can significantly enhance forecasting accuracy and improve responsiveness to demand fluctuations.

However, both the findings of the present study and prior research indicate that the implementation of such approaches is accompanied by several operational challenges. Bilal et al. (27) and Sharma et al. (28) identify key barriers, including poor data quality, a shortage of skilled personnel, and infrastructural limitations, all of which can undermine forecasting accuracy. As a result, even when advanced analytical tools are available, supply planning may remain vulnerable to considerable errors.

Overall, these findings suggest that while the transition toward intelligent and data-driven forecasting is an unavoidable necessity in crisis management, its effectiveness is highly dependent on data quality, the maturity of digital infrastructures, and the analytical capabilities of organizations. Without addressing these underlying factors, achieving optimal performance in healthcare supply chains will remain a significant challenge.

The present study further demonstrates that revising the design of distribution networks and implementing structural reforms during crises are essential for enhancing the resilience of pharmaceutical and medical equipment supply chains. Distribution networks designed for stable and predictable conditions often lack the flexibility required to respond rapidly to critical hotspots during emergencies and fail to adapt effectively to sudden shifts in demand and consumption patterns. In this context, the findings of the present study are consistent with Talaie (29), who identifies flexibility, agility, and information visibility as key characteristics of efficient distribution networks, particularly when supported by real-time data and advanced tracking technologies.

Beyond this, existing literature highlights the importance of dynamic and adaptive network redesign. Ivanov and Dolgui (11) demonstrate that the dynamic reconfiguration of supply networks is crucial for maintaining system performance under large-scale disruptions. Similarly, Queiroz et al. (30) emphasize that crises such as the COVID-19 pandemic require higher levels of agility and flexibility to respond to rapidly evolving demand patterns and emerging hotspots. In addition, Kumar et al. (26) argue that integrating digital technologies—such as real-time analytics and tracking systems—enhances supply chain visibility and supports faster, more informed decision-making. Chowdhury et al. (31) further show that supply chain resilience is strongly dependent on the ability to reconfigure distribution networks and adapt to continuously changing conditions.

Taken together, these findings indicate that flexibility, agility, and access to real-time information are foundational components in the design of resilient distribution networks. These capabilities are particularly critical for enabling rapid and targeted responses to demand surges in high-risk and resource-constrained settings.

The present study also highlights that demand forecasting in crisis settings must be dynamic, crisis-oriented, and grounded in up-to-date data, as the unique characteristics of each crisis can significantly alter demand patterns and render historical trend-based forecasts ineffective. These findings are consistent with Pang (32), who emphasizes that advanced forecasting systems can prevent disruptions in pharmaceutical supply and improve responsiveness to emergency needs. Similarly, Ivanov (11) shows that forecasting models must be based on adaptive scenarios and real-time data to capture sudden demand fluctuations. Arora et al. (33) further demonstrate that big data analytics and advanced forecasting systems play a critical role in enhancing the responsiveness of healthcare supply chains during emergencies.

In contrast, some studies propose complementary strategies. For example, Postma (34) introduces long-term stockpiling as a mechanism to mitigate uncertainty, while Badreldin and Atallah (35) highlight the role of strategic stockpiling in improving preparedness. However, these approaches are not without limitations, as they may increase holding costs, raise the risk of pharmaceutical expiration, and contribute to resource wastage.

Taken together, the evidence suggests that while stockpiling can function as a complementary strategy, its effectiveness is contingent upon integration with intelligent, data-driven forecasting systems. Therefore, hybrid approaches that combine advanced forecasting with strategic stockpiling offer a more balanced solution, enhancing resilience while maintaining cost-efficiency and operational performance.

The present study further emphasizes that deficiencies in distribution system structures can directly disrupt access to essential medicines, particularly among vulnerable populations who are disproportionately affected by delays and shortages during crises. This finding is consistent with Emanuel et al. (36), who demonstrate that resilient distribution networks are a prerequisite for effective responses to sudden shocks, and that structural weaknesses can lead to delayed delivery and adverse patient outcomes.

Similarly, Guan et al. (37) show that disruptions in global distribution networks during the COVID-19 pandemic significantly affected access to critical goods and exacerbated inequalities. Ranney et al. (38) further highlight that inefficiencies in distribution and logistics systems contributed to critical shortages at the hospital level, while Iyengar et al. (39) report that supply chain disruptions—particularly in resource-limited settings—led to reduced access to essential medicines and serious public health consequences.

These findings underscore that the efficiency and resilience of distribution networks are central to ensuring timely and equitable access to medicines during crises, and that structural weaknesses in this domain can have far-reaching implications for population health.

The study also demonstrates that the evaluation of logistics infrastructure and distribution systems must be grounded in accurate, up-to-date, and reliable data. Such data are essential for optimizing real-time decision-making, enabling timely resource allocation, and improving response efficiency in crisis situations. In this regard, the findings align with EO Alonge et al. (45), who show that strengthening data-driven systems—through improved inventory management, reduced lead times, and enhanced coordination—can significantly improve system responsiveness.

In addition, Kwon et al. (42) demonstrate that real-time data and integrated information systems enhance supply chain visibility and support faster and more accurate decision-making. Queiroz et al. (30) further emphasize that digitalization and big data analytics improve flexibility and responsiveness, while Dubey et al. (43) show that data analytics capabilities and Industry 4.0 technologies enhance logistical performance by improving coordination and reducing uncertainty.

However, as highlighted by D Al Nuaimi et al. (7), the implementation of such approaches is constrained by challenges including data integration issues, high implementation costs, and technological complexity. Similarly, Bag et al. (44) caution that these barriers may limit the full realization of data-driven supply chain capabilities.

Overall, these findings suggest that while data-driven systems are key enablers of improved logistical performance, their effectiveness depends on the maturity of digital infrastructure, organizational readiness, and the ability to manage technological complexity.

The present study also demonstrates that the absence of formal and structured processes in supply chain management can lead to an overreliance on informal relationships and unstructured decision-making, ultimately reducing the efficiency of crisis response. This finding is consistent with Bahadori et al. (46), who emphasize that systematic coordination and organizational collaboration are essential for improving information flow, optimizing resource allocation, and aligning operations.

In addition, Liu and Shi (47) show that strong network structures and inter-organizational collaboration—particularly through information integration and multi-sectoral partnerships—can significantly enhance response effectiveness. These findings are further supported by Kapucu (48), who demonstrates that inter-organizational networks improve coordination and collective decision-making when supported by flexible yet structured governance mechanisms. Similarly, Scholten and Schilder (49) and Pettit et al. (50) highlight that collaboration, transparency, and role clarity are critical determinants of supply chain resilience.

Finally, the study highlights that human resource capacity and technological capabilities are fundamental to strengthening health system responsiveness during crises. From a workforce perspective, specialized training, psychological preparedness, and effective management of occupational burnout among frontline staff are essential for sustaining system performance. As shown by Kaim et al. (51), preparedness and training significantly enhance the effectiveness of response teams, while Huang et al. (52) demonstrate that unmanaged stress and burnout can undermine system performance.

From a technological perspective, emerging tools such as artificial intelligence and big data analytics play a critical role in improving forecasting accuracy and supply chain responsiveness, as highlighted by Okonkwo et al. (53) and Liu et al. (54). However, the implementation of these technologies remains contingent upon overcoming challenges related to cost, infrastructure, and governance frameworks.

Taken together, these findings reinforce the importance of adopting a holistic and integrated approach that simultaneously addresses structural, technological, and human factors in order to enhance the preparedness and resilience of pharmaceutical and medical equipment supply chains in crisis settings.

Conclusion

In conclusion, this study clearly demonstrates that preparedness of the pharmaceutical and medical equipment supply chain in crisis settings is influenced by multiple interrelated dimensions, including needs assessment, selection and stockpiling, demand forecasting, logistics infrastructure, distribution systems, inter-organizational coordination, and human resource and technological support. The findings highlight that preparedness is not confined to maintaining physical reserves; rather, it requires systemic coherence across structural, operational, and strategic domains.

In particular, the study underscores that effective human resource management and technological capacity are decisive determinants of successful crisis response. Specialized training, psychological preparedness, and structured workforce management enhance frontline resilience, while advanced technologies—such as predictive analytics and artificial intelligence—enable accurate demand forecasting and optimal resource allocation. When integrated within a robust governance framework, these elements significantly strengthen supply chain performance during emergencies.

Furthermore, coordinated inter-organizational mechanisms and formalized resource allocation processes are essential to prevent duplication of efforts, role conflicts, and resource wastage. Weaknesses in logistics infrastructure or managerial processes can result in substantial disruptions in the availability of essential medicines and medical equipment, particularly under high-pressure crisis conditions.

Overall, this study emphasizes the necessity of a comprehensive and integrated approach that combines workforce capacity building, technological innovation, structural reform, and collaborative governance to enhance resilience and efficiency in pharmaceutical supply chains during disasters. Future research is recommended to examine the impact of intelligent forecasting models and emerging technologies on distribution system performance, as well as to explore strategies for optimizing human resource management and strengthening inter-organizational collaboration in unexpected crisis scenarios.