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Resilient Emergency Procurement Strategies and Quantitative Metrics: A Review †

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Abstract: The growing frequency and complexity of both natural and man- made crises like pandemics have highlighted the need for robust emergency logistics strategies during the last decade. Procurement is one of the critical areas impacting any emergency supply chain. Dealing with disruptions usually involves multi-sourcing, option contracts, and back-up suppliers as resilient strategies. The proposed review classifies emergency procurement strategies into three capacities following the capacity resilience framework: absorptive, adaptive, and restorative. Also, quantitative resilience metrics, modelling methods, and objectives for practical scenarios are discussed. Conclusions are extracted, and future research agendas outlined.

Keywords: emergency procurement; resilience metrics; resilience capacity; mathematical modeling

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1. Introduction

In today's VUCA world—volatile, uncertain, complex, ambiguous—marked by the rising occurrence of natural and man-made disasters, the resilience of emergency supply chains has been taking on increasing importance. Within an emergency context, procurement plays a critical role in maintaining stability and ensuring supplies reach the affected areas at the right time.

The fact that procurement is located at the front lines of a supply chain makes it the most important area to focus on within research. It means that, in the occurrence of a disruption in procurement, the ripple effect would trigger [1]; hence, its impact would propagate throughout the entire supply chain, affecting various nodes, instead of staying confined to one part of the supply chain, ref. [2] describes that if the ripple effect phenomenon happens in procurement, it might affect the whole supply chain resilience.

Emergency procurement strategies such as multiple sourcing, supplier diversification and backup suppliers have been developed to help consolidate the procurement emergency supply chain resilience during disaster phases [3]. These different strategies can be categorized by the three resilience capacities [4]: absorbative in minimizing the impact from a disruption, adaptive in adjusting operations and restorative in rapidly getting back to the original state.

While previous research papers have used the concept of resilience capacity to explore general supply chain resilience, there is no existing literature that has explored emergency procurement resilient strategies. This focus is of major importance, given procurement

plays a critical role in guaranteeing the availability of indispensable relief items during crisis situations. Literature reviews, such as [5] have pointed out the need for an extension to explore procurement resilience in high-stakes emergency contexts. Moreover, it is important to have quantitative metrics in the assessment of the overall supply chain performance in responding effectively to emergencies. Therefore, the quantification of resilience metrics is important for comparing the recovery capabilities of systems under disruption [6]. One of the success factors in literature reviews is formulating clear research questions, as they guide the reader and outline the scope of the study. This paper is structured around the following questions:

Q1: What are the most common procurement resilience strategies applied in each type of resilience capacity?

Q2: How does the literature quantify resilience?

Q3: What gaps and future directions need more focus?

2. Methodology

2.1. Search Scope and Focus

Recent pandemics and natural disasters have driven major evolution in supply chain resilience over the last ten years. This proposed review will focus on research between 2014 and 2024 studying the strategies of resilience in procurement operations in crisis times. Quantitative models of resilience, metrics, and the categorization of resilience strategies into absorptive, adaptive, and restorative capacities are analyzed.

2.2. Initial Search Strategy

The search was carried out in two databases: Scopus, an ScienceDirect to find peer-reviewed articles offering diverse insights into resilience strategies in emergency procurement.

2.3. Search Keywords and Boolean Combinations

A specific Boolean search using research scope terms was done to find related studies.

Emergency Logistics: (“emergency procurement” OR “emergency supply chain” OR “emergency logistics”) Resilience metrics: (“resilience metrics” OR “resilience strategies” OR “resilience capacity” OR “quantitative models” OR “objective functions”)

The research resulted in a total of 337 articles, obtained from a search on these two databases. The papers were carefully filtered through defined inclusion and exclusion criteria that narrowed the studies within the scope of this research.

2.4. Inclusion Criteria

Research published between 2014 and 2024. Focus on emergency procurement, logistics, or supply chains during disasters or pandemics, not commercial supply chain. Incorporation of mathematical models or frameworks with measurable resilience applications. English Articles.

2.5. Refinement Process

Screening: The objectives of the study were screened first through the titles and abstracts for the exclusion of irrelevant studies. Then, a detailed review of full-text articles was carried out.

Final Selection: This process resulted in 21 articles from the ScienceDirect database and 10 from the Scopus database, for a total of 31 articles chosen for in-depth review.

Based on this, the research methodology selected 31 for a detailed analysis. The selected studies give different resilience strategies related to emergency procurement. They

also include quantitative metrics and modeling approaches that have been used within the context of a emergency resilience supply chain.

3. Results and Discussions

3.1. Data Visualization Analysis of Literature Review

The following section presents data visualization to analyze emerging trends in resilience strategies related to procurement during crisis.

3.1.1. Keywords

The analysis reveals that "humanitarian supply chain" is the most frequent keyword, followed by "uncertainty" and "disaster". It is worth noting that "Emergency supply chain" and "Humanitarian supply chain" are often used interchangeably, as illustrated in Figure 1.

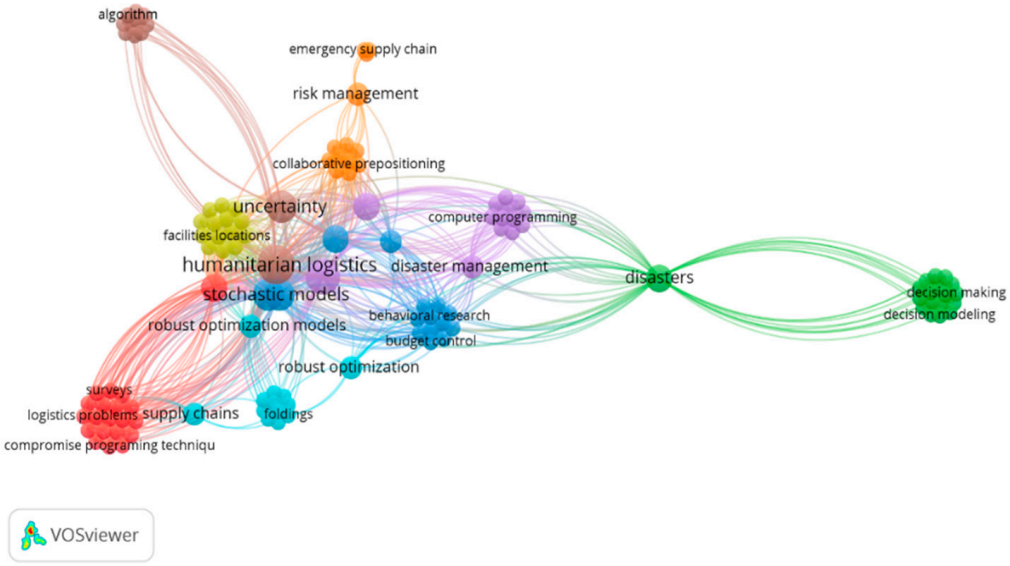


Figure 1. Keywords visualization using Vos viewer 1.6.20 software.

Connections: Keywords such as "disasters" are strongly linked to "decision making" and "decision modeling" highlighting the importance of strategic decision-making in disruptions.

Models: Terms such as "stochastic models" and "robust optimization" underline most used approaches in modeling uncertainty in emergencies.

Other themes: "Facility location", "budget control", and "collaborative repositioning" show also emerging areas in the literature.

3.1.2. Papers Publication Evolution

Figure 2 represents the evolution of publications, showing an increasing trend for procurement-related documents pertaining to the emergency supply chain. It indicates a gradual, high-level rise from 2016 into 2024, showing the development of higher complexity or increased activity and interest of scholars in emergency logistics aligned with the increasing frequency of disasters, namely the COVID-19 global health pandemic.

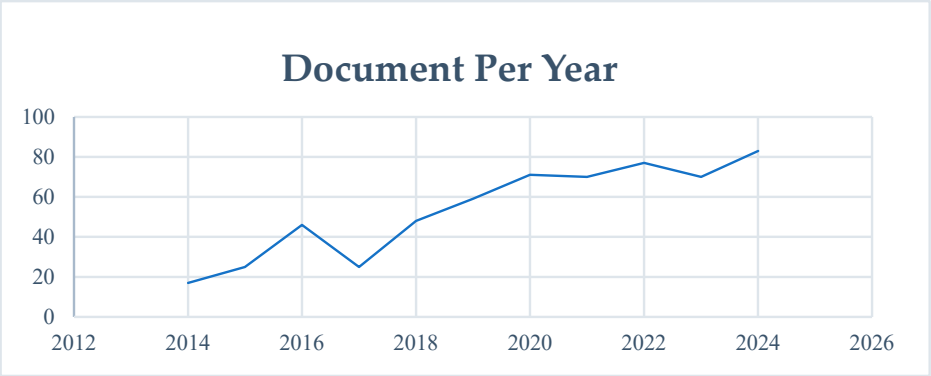


Figure 2. Papers publication evolution (2014–2024).

3.2. Absorptive Capacity

In the view of extreme conditions to deliver vital supplies and resources to areas of need during disasters, absorptive capacity strategies will be necessary for emergency supply chains to ensure effective response and continuity.

3.2.1. Supplier Diversification and Dynamic Supplier Selection

The high frequency of climatic disasters, such as hurricanes and floods, has driven the urgent need for diversified supplier networks in emergency supply chains. In addition, geopolitical challenges like conflicts or border restrictions generally disrupt emergency logistics. This is because, in disaster-prone areas, reliance on one supplier may lead to critical shortages during crises. The studies benchmarking proactive and reactive strategies to improve supply chain resilience regularly identify supplier diversification as one of the key strategies [7,8]. Reference [9] particularly underlines the efficiency of supplier diversification for the geographical spread of the sourcing risk of the relief supplies and reduction in the dependencies of vulnerable supplies. This strategy works only if, according to [10], suppliers are pre-screened during the selection process based on their ability to perform under stress; otherwise, diversification won't help in major disruptions.

3.2.2. Multi-Sourcing

The COVID-19 global pandemic revealed the fragility of single-source dependencies particularly for critical medical and food supplies [11]. By multiplying supplier channels multi-sourcing can mitigate dependency risk [12]. Game theory can improve this strategy by modeling supplier interactions to allocate resources efficiently. For example, ref. [13] demonstrates how game theory can guide fair workload distribution among suppliers in mutual affected regions, ensuring faster delivery and minimizing redundancy. Similarly, reference [14] apply game-theoretic models to dual sourcing which can be considered as a subset of multi-sourcing, showing how competition between suppliers can improve responsiveness while balancing cost and relief items availability.

3.2.3. Inventory Pre-Positioning

The necessity for rapid aid delivery during emergencies and crises has made pre-positioned inventory a major strategy in emergency logistics. Repositioning supplies in areas of high risk tend to bring response times down significantly [15]. For instance, ref. [16] uses scenario-based models for determining the best siting for pre-positioned inventories. Similarly, ref. [17] applies a decision support system to decide where and how much stock to store, thus allowing reduction of last-minute responses. Ref. [18] suggests a decision-making model directed toward ensuring the timely arrival of aid to the purporting areas.

3.3. Adaptive Capacity

3.3.1. Optional Contracts

Flexibility and adaptability are especially crucial in the procurement processes in emergencies when the resources are limited, and demands are unpredictably changed. Option contracts, especially bidirectional, could address some of the flexibility issues, enabling the emergency organizations to turn up or scale down their orders [19]. This would avoid both overstocking-those results in wasting resources-and understocking, which causes delayed responses. Reference [20] demonstrate that option contracts make supply chains resilient and enable quick responses to disruptions and improve social efficiency. To facilitate this process, decision-makers rely on mathematical models that are designed to address uncertainty, such as stochastic programming. For instance, option contracts are used in the model presented by [21] to balance cost and responsiveness. The model minimizes procurement costs and maximizes flexibility costs. Flexibility is at the heart of adaptive capacity. During crises, organizations can not exactly predict how much supplies are needed, therefore paying for the option to procure more resources ensures the system adaptability and resilience.

3.3.2. Backup Suppliers

In times of crisis, when the main suppliers fail, backup suppliers ensure alternative supplies are available, acting as a safety net. This falls in alignment with the adaptive defense line of the resilience concept, which enables the flexibility to switch to alternative options swiftly during emergencies. Paper [22] confirm that backup suppliers are important in the context of disruptions to mitigate risks and improve supply chain resilience. In emergency, pre-positioned stock of supplies (Absorptive capacity) may be insufficient or unavailable. At this point, adaptive capacity is triggered through back up suppliers' strategy to achieve responsiveness and resilience. [23], addresses the importance of ensuring continuity in relief distribution by activating backup suppliers in case of supplies shortage to meet affected populations urgent and unpredictable demand. This approach was incorporated in the paper's two-stage stochastic model by adding up backup suppliers to the cost structure.

Procurement cost: Sourcing from both primary and backup suppliers

Transportation cost: Moving supplies from back up suppliers' sources to affected arears.

The proposed approach was incorporated in the model's constraints, as follows:

- Demand Fulfilment: $\sum_i Q_i + \sum_j Q_j \geq D$
- Ensures that the total supply from both primary and backup supplier, meets the demand D, even under disruption.
- Capacity Constraints: $Q_j^{Backup} \leq Capacity_j$
- Ensures realistic sourcing by considering the backup supplier logistics limitations.

Integrating the backup supplier option as a resilience strategy, as shown in the model, can increase costs, as a result straining the overall supply chain allocated budget. Also, since a crisis requires an immediate response, there must be great coordination between the suppliers themselves and the readiness of the backup suppliers for the fast and effective activation of the back-up supplier as demonstrated by [24] where backup suppliers were assigned to affected areas to improve the model reliability. To address the above-mentioned challenges, dynamic supplier assessment is an effective way to make sure that back-up supplier selection is carried out considering not only general reliability but ability to respond

under emergency, considering variables such as: capacity under stress and humanitarian standards' compliance [25].

3.4. Restorative Capacity

To ensure a speedy recovery upon the striking of any disruption, restorative capacity should be primary focus. The review literature such as [26] underlines the employment of stochastic modeling to evaluate the impacts that long-term contracts and predictive analytics have on mitigating the occurrences of disruptions and quick recoveries. In a similar light, ref. [27] quantifies resilience so that decision-makers can adopt a path of quick and sustainable recovery through a case study to manage a fire event in a hospital. The following paragraph delves into the most common resilience strategies found in literature, categorized by their main objectives.

3.5. Resilience Metrics

In the recent past, assessment and measurement of resilience has been a focal point of researcher efforts. Researchers have either proposed direct or undirect measurement of resilience. Ref. [28] suggested indirect approaches for measuring the resilience of a supply chain, by defining resilience across different phases: prior to, during and following a disruption and by considering four key dimensions: reliability, robustness, recovery and reconfigurability. On the other hand, specific resilience metrics have been proposed by scholars to assess the system ability related to withstanding (absorptive capacity), adapting (adaptive capacity), and recovering (restorative capacity) from disruption [29]. Various key objectives are considered in designing a robust supply chain network, each supported by a specific resilience line. Specific resilience metrics can be clustered into major objectives based on the growing body of literature as shown in Figure 3.

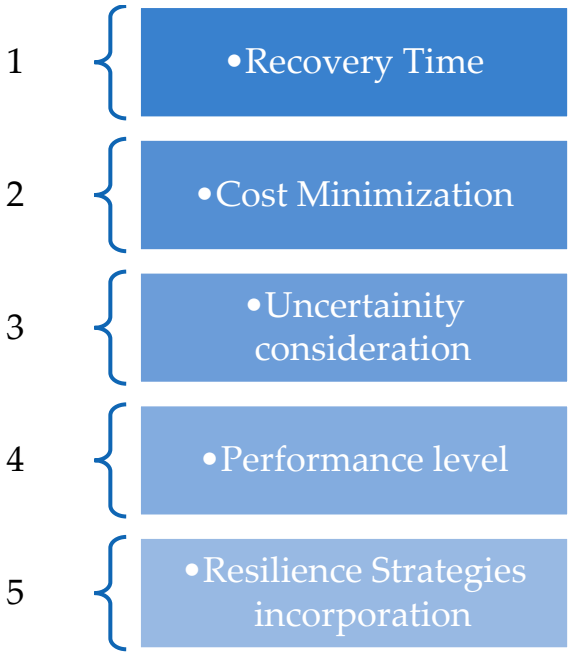


Figure 3. Objectives of a resilient Supply chain Network.

Recovery Time: By applying the TTR metric that means time to recovery- a time needed to get operations back into their original state [30].

Cost minimization: This includes the reduction of direct and indirect costs to mitigate a disruption [31].

Uncertainty consideration: This encompasses the adoption of modeling approaches approved to consider the uncertainty dimension, for instance, stochastic, robust programming [32,33].

Performance level: by assessment of the service level, making sure it is sustained even after a disruption has occurred [34].

Incorporating resilience strategies: focusing on adaptability, speed, and robust partnership to ensure collaboration between the network stakeholders for minimizing disruption impacts [29].

4. Conclusions

This study highlighted that resilience in procurement is one of the important parts of emergency supply chains. This paper reviewed 31 papers from the last decade that group procurement strategies into three resilience capacities: absorptive, adaptive, and restorative.

The main strategies for developing absorptive capacity include supplier diversification, dynamic supplier selection, multi-sourcing, and pre-positioning of inventories to handle disruptions as they arise. While adaptive capacity focuses on flexibilities through option contracts or backup suppliers that can quickly respond to challenges, restorative capacity is focused on fast recovery through contingency plans and effective recovery strategies. The paper went further to link the above strategies with specific resilience metrics and indicated the lapses of how resilience is measured and assessed.

This work emphasizes state-of-the-art methodologies concerning Bayesian networks and multi-objective models for the preparedness, response, and recovery phases of disasters. Besides, some suggestions are thrown regarding the focus on topics that might be of higher interest: among them, interrelation between sustainability and resilience, digital tools within procurement based on smart contracts, application of AI, and machine learning in tracing demand in real time during crises.

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