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Strategies for Achieving Pre-emptive Resilience in Military Supply Chains

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Abstract

As technological advancement is rapidly evolving modern warfare, military supply chains are becoming more dynamic and complex with high vulnerability to unexpected disruptions. To increase their overall resilience against such unexpected disruptions, traditional approaches are no longer sufficient. To date, research on supply chain resilience has mainly focused on reactive responses and recovery strategies (post-disruption). Hence, the research gap addressed in this paper is that of identifying new and proactive strategies to enable pre-emptive resilience in military supply chains (pre-disruption). In this paper, the authors first provide a critical review of the pertinent literature and research conducted over the past 12 years. Following on from there, they identify new research directions for enabling pre-emptive resilience to aid military logistic planners in monitoring supply chains and strategic decision-making to maintain their resilience.

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Keywords: Military supply chain; Supply chain disruptions; Pre-emptive resilience; Simulation; Mathematical modelling; Decision support; Digital twin

1. Introduction

Military supply chains (MSC) are the life line of militaries in warfare. As such, these supply chains are dynamic and operate within an uncertain environment susceptible to man-made or natural disasters such as enemy strikes and sabotage, earthquakes, tsunamis, floods, etc. To boost the chances of success in warfare, it is necessary for military logistic planners to employ proactive strategies towards improving its supply chain resilience. Building resilience is a strategic manoeuvre and helps organizations anticipate disruptions and adapt to new post-event states [1, 2]. According to Hollnagel [3], a system's pre-emptive resilience capability is described as the ability to perceive, anticipate, and defend against changing risk forms before negative consequences occur. Although, numerous scholars have attempted to improve MSC resilience, however, most of them are focused on reactive resilience (post-disruption) aimed at ensuring swift recovery after impact. Furthermore, several approaches have been employed to improve supply chain resilience against disruptions and have proven to be insufficient [4]. Strategies such as creating redundancy can be an expensive means of building resilience. For example, spare capacity is needed along the critical path to reduce potential vulnerability and build resilience [5]. Also, supply chain visibility as a resilient strategy using mixed integer programming has been utilized on numerous occasions to analyse supply chain disruptions. However, these strategies are limited mainly by not being able to accommodate the dynamic nature of supply chains in terms of duration or irregular impact and therefore allowing for many assumptions [6]. Hence, the need for a proactive resilient strategies that accommodates the inclusion of uncertainties that reflects scenarios of events that yields optimal solutions especially in complex and dynamic supply chains like the military supply chain.

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The aim of this paper is to identify strategies for achieving pre-emptive resilience in military supply chains. This is particularly beneficial for researchers, logistic planners, and military commanders seeking to manage supply chain disruptions using pre-emptive strategies. The scientific contribution is to reveal where there are gaps in the area of pre-emptive strategies for managing supply chain disruptions, current pre-emptive strategies used in the military supply chain, and also possible areas of further studies.

The organization of the paper is as follows. In Section 2, effects and mitigating strategies of disruption on military supply chain is given. In Section 3, pre-emptive resilience measures for managing military supply chain disruptions is highlighted. In Section 4, modelling approaches to military supply chain disruptions is illustrated. In Section 5, The role of digital technology tools in managing supply chain disruptions is discussed. In Sections 6 and 7, challenges and future research opportunities and closure are presented respectively.

2. Disruptions in Military supply chain

Supply chain disruptions are defined as a combination of an unanticipated triggering event and the subsequent effects that risk material flow and normal business operations significantly [7]. These disruptive triggers can be classified into “Natural (earthquake, floods, fire, etc.) and man-made (terrorist attacks, accidents, supplier insolvency, etc.)” [8]. In the military supply chain, the above disruptions exist alongside demand variations in volumes and types. As a priority target, military supply chain often face disruptions since it often operates in uncertain and risky environments. For example, a disruption may initially destroy or disable only one or few entities in the system, but its impact may propagate further, sometimes even with amplifications, among interconnected entities. Such disruption will thus affect the normal operations of the supply chain [9]

2.1 Effects of disruptions on the military supply chain

To live or win in combat, the armed force needs supplies (such as food, water, and fuels) [9]. Such supplies may be subject to natural calamities, social crises, and terrorism with a high chance of jeopardizing the overall success of the operation. For example, in Iraq and Afghanistan, the US military faced a gasoline scarcity, which hampered its efforts to win the war at the onset (National Public Radio 2011).

2.2 Strategies for mitigating military supply chain disruptions

Supply chain disruptions must be identified in a timely manner in order to implement an appropriate mitigation strategy [10]. Similarly, management strategies in SC supported by models and data from enabling technologies can identify risk, assess risk, and monitor deviation. They can also recognize the early warning signal to prepare for interruptions [11, 12]. An example of process for managing supply chain risk is presented in Figure 1.

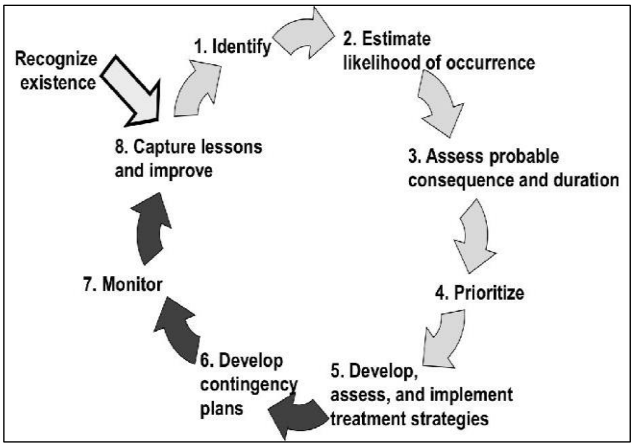

Fig. 1. Process for managing supply chain risk [11].

In order to mitigate supply chain network risks, Hopp [12] introduced backup capacity comprising of ‘subtree capacity protection and single-node capacity protection and inventory protection as protection strategies at the pre-disruption stage. In agreement, Zhang [13] investigated pre-disruption strategies such as the combined protection mechanism (capacity backup protection and inventory protection), against endogenous attacker efforts in a defender-attacker game. Their findings showed that these strategies can help the defender in counter-terrorism games. Further studies on a protection plan for a ‘multi-period inventory’ combined with a defender attacker game that is in multi-period and multiple-resource model was suggested. Loredo [11] for RAND corporation California USA identified disruptions in supplier, demand and process and suggested how they can be prevented to support Army Material Commands (AMC). The strategies by the above authors have been summarised in Table 1.

Table 1. Strategies for mitigating military supply chain risk.

Authors	Risks	Strategies
Xu et al. (2016)	Enemy attack	Capacity backup protection, inventory protection
Loredo et al. (2015)	Supplier risk	Suppliers’ evaluation, selection (via certification and prequalification), and monitoring or auditing for viability, quality, dependability, penalize poor performance, promote good performance, and encourage collaboration and knowledge exchange.
	Demand risk	Develop industry standards, form building blocks for common product and joint forecasting.
	Process risk	Adhering to international organization of standards (ISO) 9000 standards for process control, supply chain visibility improvement, and lead-times reduction.

3. Pre-emptive Resilience measures for managing military supply chain disruptions

Some studies highlighted the importance of establishing resilience capabilities early on, such as flexibility, visibility, robustness, redundancy, collaboration, catastrophe preparedness, financial strength, and market capability, amongst others [11, 18-21]. According to Simon [4], their understanding of resilience dependents on the measure of robustness and flexibility. The relationship between some of the above measures and strategies to mitigate supply chain disruptions is shown in Figure 2.

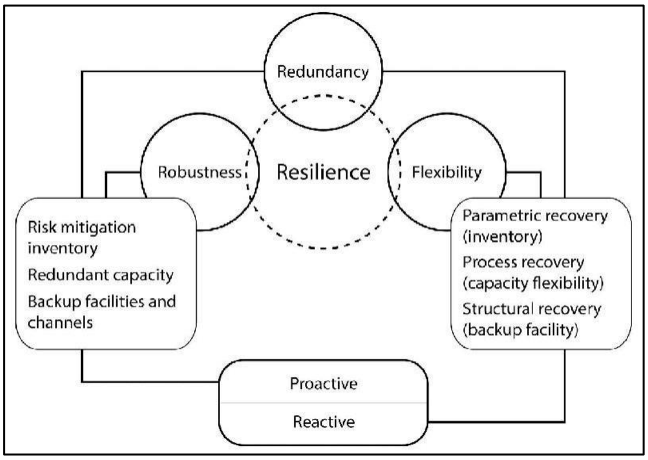

Fig. 2. Resilience measures with supply chain mitigation strategies [4].

Al Naimi [14] suggested safety stockpiles and source diversification as approaches to increase supply chain resilience. This is demonstrated by the US Defense Department, which released around 5 million masks from its stockpiles in March 2020 to aid in the fight against the COVID-19 pandemic. The release of the masks from its stockpiles was a pre-emptive strategy able to meet immediate needs and reduces the waiting time for masks production. Additionally, Jensen [15] and Tsai [16], stated that the use of multiple suppliers facilitates prompt delivery of products and protects against disruptions in supply chain, particularly when there is a possibility of a single supplier failing [17]. Sokri [18] evaluated the military supply chain's flexibility by developing performance measures to evaluate volume flexibility (the capacity to modify the number of products moved) and delivery flexibility (the ability to attain the quick lead times). In military SC, attributes of each demand is based on expected delivery day and a priority code hence the need for flexible mode of transport or distribution [18]. Similar strategies were found in a study by [19] of pharmaceutical supply chains in Morocco where multi-sourcing, and flexibility in transport mode were the proactive strategies used for mitigating disruptions. Another study [20] mentioned flexibility as a proactive strategy to mitigate supply chain vulnerability an apparel industry in Bangladesh.

Sokri [18] further suggested that studies be carried out on a “multi-objective time–cost-volume trade-off”, which seeks to minimize the delivery time and cost. Reinders [21], investigated robustness as a mitigating strategy for supply and demand uncertainty disruptions in the supply chain of the royal Dutch land forces. The research used stock level, order-fulfilment and lead time as key performance indicators for measuring the extent of robustness. It is indicated that a robust supply chain can survive higher levels of supply and demand unpredictability. Bordetsky [22], designed an experiment using system theory to explain how stock levels is affected by collaboration on logistics information in the supply chains among companies and military organizations in a tactical operating environment. In the experiment, they demonstrated a better understanding of how the effectiveness of a supply chain can be increased by an increase of collaboration in the supply chain. Additionally, collaboration in form of information sharing, IT tools, and infrastructure with players in the supply chain in manufacturing, personal care businesses, pharmaceuticals, etc have shown to have helped in predicting and preventing possible future disruption risks, detection of supply chain failures, and improved visibility [23-26].The resilience measures and the key performance indices (KPIs) used are summarized in Table 2.

Table 2. Resilience measures and KPIs

Authors	Resilience Measures	Key Performance Indicators
Al Nami (2020)	Redundancy	Safety stockpiles and source diversification
Sokri (2014)	Flexibility	Volume and delivery flexibility
Reinders (2019)	Robustness	Stock level, order-fulfilment and lead time
Bordetsky and Ascef (2013)	Collaboration	Stock levels

4. Modelling approaches to military supply chain disruptions

4.1. Modelling approach

Military logistic planners should be able to model and predict supply chain disruptions in a proactive way instead of reactive for the purpose of solving disruptive event problems. Mathematical models are capable of capturing patterns of data from events that had occurred before for the purpose of projecting the patterns so that future outcomes can be simulated [6].

4.2. Modelling and simulation of the military supply chain disruptions

For a military peacekeeping operation, Ryczynski and Tubi [27] developed a risk analysis method that incorporates the Kaplan and Garrick approach as well as fuzzy theory to build the resilience of the fuel supply chain. The study locates existing disruptions and allocates them to specific segments of the supply chain. They stated that the method can be generally applied by planners in making decisions where risk conditions are high. Kaddousi and Zoghlami [28] proposed a general agent framework for disruption management optimization for the military with the goal of reducing the impact of disruptions and uncertainty in a 'highly distributed crisis management supply chain' using a disruption management agent (DMA) with a watch agent that prompts alarms when a disruption event is detected. Their work aimed at deploying military logistics such as food, water, medicals, personnel, vehicles and sustain them in the course of operation. Similarly, for the purpose of military logistics deployment, Salmeron and Morton [29] developed a stochastic mixed integer programming model for deployment planning of U.S sealift cargo delivery in war time to proactively provide probabilistic information on the time and locations of potential enemy attacks on seaports of debarkations (SPODs). The results showed that with their model, the expected total disruption was reduced by 8% and proven to be more effective than rule-based planning.

Rogers [30], designed a Military logistics network planning system (MLNPS) as an app on the Army's enterprise resource planning (ERP) system (Global Combat Support System-Army), to identify and mitigate logistical problems prior and during military's operations. They claimed that the impacts of an approaching storm on logistical network can be predicted using the MLNPS to allow commanders time for the network adjustments to reduce the impacts. Zhao [31] studied the resilience of complex supply network topologies against random and targeted disruptions using a military logistic network as a case study. They presented Degree and locality-based Attachment (DLA), a hybrid and customizable network growth model in which new nodes create connections based on both degree and locality. They discovered that the DLA model's supply network design provides balanced resilience against both random and targeted disturbances. Based on the new resilience metrics of availability and connectivity used by the authors, there is a good resilience against random disruptions. However, it is posited that their resilience against targeted disruptions is not adequate despite the fact that it has high probability of occurrence.

Xiong [32] described the modelling of military supply chain networks using Arena Simulation, with a focus on evaluating their effectiveness, especially under conditions of disruption. They simulated a POL (Petrol, Oil and Lubricant) network to solve the problem of supply chain network effectiveness evaluation from the perspective of dynamic and discrete networks. By applying the model and algorithms to a POL supply network in a theatre, they obtained the values of supply capability and efficiency metrics in a dynamic environment. Their results show that new evaluation metrics can capture important effectiveness requirements for military supply networks positively.Kim and Moon [33] designed a new "Parallel Model" to replace the "Substitute Model" in Republic of Korea Military Supply system. Analysis of the two models' critical factors in warfare; the supply line's destruction ratio and the mean of demand using in-system dynamics simulation showed that the parallel supply model was a more resilient and effective method in the MSC. Sethi and Sharma, [34] dwelled upon the conceptual development of an ideal performance measurement framework for the military supply chain and discussed some of the principal performance measurement frameworks, like the Balanced Scorecard and Supply Chain Operations Reference model (SCORM). Rosetti [35] described the conceptual modelling of bulk petroleum supply chains for the U.S Defense Logistics Agency under contingency planning scenarios such as increased surge demand and disruption events. Their methods, insights, and capabilities developed facilitates the analysis of bulk petroleum military supply chains and also permit the analysis of the resilience of commercial bulk petroleum supply chains under conditions of disruption. The modelling approaches used in the military supply chain are summarised in Table 3.

Table 3. Summary of modelling approach for military supply chain.

Authors	Focus	Disruption	Model
Zhao et al. (2011)	Resilience	Random and targeted	DLA
Kaddoussi et al. (2011)	Disruption management	Risks and uncertainties	DMA
Rogers et al. (2018)	Network planning	Random and Targeted	MLNPS
Ryczyński and Tubis (2021)	Resilience	Exogenous and Endogenous	fuzzy theory
Salmeron and Morton, (2021)	Planning	Targeted	SMIP
Xiong et al., (2017)	Effectiveness	Targeted and Random	Arena Simulation
Kim and Moon (2017)	Resilience	Targeted and Random	In-system dynamics simulation
Sethi and Sharma, (2018)	Performance	Targeted and Random	SCORM

5. Role of digital technology tools in managing supply chain disruptions

Today's supply chain managers are faced with an overwhelming amount of data, which may enable new ways of organizing and analysing supply chain processes to boost supply chain performance [36]. Recent research pointed to the new opportunities for managing SC disruption by data-driven approaches such as blockchain, digital twin and Internet of military things [37-41].

5.1 Blockchain

Blockchain has emerged as a new distributed information technology; it represents a new approach in supply chain, where visibility and transparency of product flows are the principal challenges. A blockchain is a type of Distributed Ledger Technology (DLT) that records and shares all transactions that occur within the blockchain network. The blockchain network consists of multiple nodes that maintain a set of shared state and perform transactions modifying the states [42]. Blockchain technology has the capacity and flexibility to be applied to different SCM contexts. For instance, tracking and providing visibility through the entire supply chain optimises the information flow and generates cost reduction [43]. In supply chains, block chain has also been used to improve traceability by Song, Sung [44]. This attribute in a study by Syarifah [45] was used to track and monitor the movement of naval spare parts and third parties from supplier to depot.

5.2 Digital Twin

The concept of Digital Twin (DT) in a supply chain allows the design of a mirror simulation model of all processes along the supply chain. The digital twin allows to create a continuous cycle of improvement and adjustment of the entire supply chain in near-real time [46]. In recent years, the Digital Twin concept has been incorporated into industrial activities and is among the key factors for the design of the industry of the future [47]. According to Boschert and Rosen [48], the Digital Twin is the next level of simulation and is quickly becoming a key decision-making tool. Moshood [49] in a recent review evaluated how the visibility of a logistic supply network organizations can be improved using Digital Twin. According to the findings of the study, digital twins would aid firms in developing 'predictive metrics, diagnostics, predictions, and physical asset descriptions' for their logistics. This is demonstrated in the attempt by the U.S. military to secure the supply chain of their semi-conductors by using digital twin capability to validate their integrity [50]. In addition, any disruption can be spotted by a risk data monitoring tool and transmitted to the simulation model as a disruptive event. Digital twin of the SC can monitor the transport, inventory, demand and other functions of the companies in real time, allowing timely decisions to be made [41,51-53].

5.3 Internet of Military Things

The Internet of Military Things (IoMT) is a class of Internet of things for combat operations and warfare. It is a complex network of interconnected entities, or "things", in the military domain that continually communicate with each other to coordinate, learn, and interact with the physical environment to accomplish a broad range of activities in a more efficient and informed manner [54]. The concept of IoMT is largely driven by the idea that future military battles will be dominated by machine intelligence and cyber warfare and will likely take place in urban environments. The IoMT creates game-changing opportunities and supports military supply chain management from many perspectives, such as improve supply chain visibility and transparency, increase adaptability to changes in demand or supply and achieve new levels of risk management by prediction of disruptions[54]. Similarly, the combination of RFID tags, IOT sensors and 'automated data delivery systems' aids in the tracking of military supplies such as; food, fuel, and weaponry to ensure reliability in delivery and improving visibility [55].

6. Challenges and future research opportunities

During the critical review, challenges and future research opportunities are identified as follows:

- Mathematical approaches have shown to have improved resilience for both targeted and random disturbances but still showed difficulty in predicting these disturbances [31].
- Stochastic mixed integer programming model have been used to provide probabilistic information on time and locations of potential enemy attacks[28]. However, reductions in the total expected disruptions is still minimal.
- The emergence of digital technology tools like digital twin, blockchain and IoMT has further opened a new frontier of proactiveness through real time monitoring and efficient decision making [37-41].
- Flexibility studies on the performance evaluation of the military SC on a "multi-objective time – cost-volume trade-off" that seeks to minimize the delivery time and cost needs to be studied [18].

The following potential research opportunities are suggested.

- Customer satisfaction can be improved by the ability to deliver products within the minimum time [50]. This factor known as lead time is yet to be fully studied or explored in the MSC.
- Modelling supply chain disruptions by visualizing proactive and reactive processes through simulation is yet to be explored extensively.
- Potential future research could focus on the development of a Stochastic programming modelling as a decision support tool for achieving pre-emptive resilience in MSC.
- There is limited literature on supply network design embedded in the concept of digital twin for visibility and real-time monitoring [46].
- The internet of military things (IoMT), should be integrated into decision support models for information gathering and real time monitoring of SCs to manage disruptions [54].

- Blockchain technologies have the capacity and flexibility to be applied to different supply chain management contexts. This can be applied in the military supply chain for instance, tracking and providing traceability as well as security through the entire supply chain [43].
- Studies on supply chain resilience against targeted and random terrorist attacks are yet to be investigated [31].

7. Closure

In this paper, a critical literature review of military supply chain is presented, aimed at identifying pre-emptive resilience-enhancing measures of mitigating MSC disruptions. Resilient measures including key performance indicators for managing MSC disruption are identified. Quantitative model approaches for managing SC disruptions in MSC are highlighted with their corresponding impacts on the supply chain. It is found that; disruptions in the military supply chain such as terrorism, natural disasters and the likes can jeopardise military efforts in wining wars [9]. Backup capacity protection, inventory protection, stock piles, source diversification are some of the pre-disruption strategies for managing disruptions and improving resilience in the military supply chain. Robustness as a pre-emptive strategy in the military supply chain can enhance the survival of higher levels of supply and demand unpredictability. The effectiveness of a supply chain can be increased by an increase of collaboration and information sharing in the military supply chain. Modelling of supply chain disruption in the military supply chain is rare and the analysis of the model approach shows the possibility of predicting and reducing disruption on military supply chain significantly while assisting decision makers attain a satisficing solution prior to disruption. Finally, we suggest extensive research to focus on integrating digital twins in military supply chains to improve visibility and facilitate real-time monitoring in the face of unexpected disruptive event.

CRediT author statement

Shehu Sani: Conceptualization, Investigation, Writing - Original Draft, Writing - Review & Editing. **Dirk Schaefer:** Writing - Review & Editing, Supervision. **Jelena Milisavljevic-Syed:** Writing - Review & Editing, Supervision.

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