

# Towards Defence Supply Chain Resilience – A Prestudy of the Swedish Defence Sector

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## **ABSTRACT**

*Layered resilience has received increased attention in recent years. This paper addresses an important subset of layered resilience, which is resilience in defence supply chains. The paper reports on findings from two studies, conducted in the Swedish defence sector. The purpose of the two studies is to identify feasible solutions for how the Swedish defence sector can redesign its supply network to meet the new challenges of a re-established Swedish Total Defence. The first study used a modified Delphi technique and concluded that two Delphi panels constitute a useful modification to the Delphi technique. Two panels increase the validity of the results and can potentially lead to interesting outcomes that a traditional design is less likely to produce, particularly if combined with presenting the panels with statements from different perspectives and using workshops to discuss the findings. The second study used a survey to investigate which tactics for resilience in defence supply chains defence authorities and defence industry prefer in peace, crises, and war. Though inconclusive, the findings indicate that authorities and companies agree that multiple sourcing and pre-storage of supplies are important tactics to achieve resilience in defence supply chains. This is in line with previous research in commercial supply chains, which identifies increased safety stock and multi-sourcing as two of the most commonly used tactics to address disruptions.*

## **1.0 INTRODUCTION**

Beginning with the 2008 Russo-Georgian War and intensifying with the Russian annexation of Crimea in the 2014 Russo-Ukrainian War, the Swedish position on defence and security policies gradually shifted [1]. The Swedish Defence Bill of 2015 marked a definitive turning point, stating that “The most important priority in the defence bill covering the period from 2016 to 2020 is to increase the operational warfighting capability of the Armed Forces and to ensure the collective force of the Swedish Total Defence” [2]. Sweden defines its Total Defence as “the preparations and planning required to prepare Sweden for war” and in highest alert, “all societal functions are defined as Total Defence, which consists of military defence and civil defence” [3]. The current Swedish Defence Bill establishes that “The security situation in Sweden’s neighbourhood and in Europe has deteriorated over time,” continues to observe, “An armed attack against Sweden cannot be ruled out,” and emphasises that “It is particularly important that work to strengthen resilience in the most important societal functions is further developed and deepened” [4]. As of 24 February 2022, the security situation in Sweden’s neighbourhood has deteriorated even further. As a result, on 16 May 2022 the Swedish Government, with broad support in the Swedish Parliament, decided to apply for NATO membership [5].

NATO membership entails adherence to the North Atlantic Treaty in its entirety, including Article 3, which states that “In order more effectively to achieve the objectives of this Treaty, the Parties, separately and jointly, by means of continuous and effective self-help and mutual aid, will maintain and develop their individual and collective capacity to resist armed attack” [6]. NATO demands that “Each NATO member country needs to be resilient to resist and recover from a major shock such as a natural disaster, failure of critical infrastructure, or a hybrid or armed attack. Resilience is a society’s ability to resist and recover from such shocks and combines both civil preparedness and military capacity” [7]. The Warsaw Summit in 2016 specified NATO’s seven baseline requirements for national resilience. They are:

- 1) Assured continuity of government and critical government services;
- 2) Resilient energy supplies;
- 3) Ability to deal effectively with uncontrolled movement of people;
- 4) Resilient food and water resources;
- 5) Ability to deal with mass casualties;
- 6) Resilient civil communications systems; and
- 7) Resilient civil transportation systems [8].

At the Brussels summit in 2021, NATO “pledged to expand innovation, resilience, adaptability, and a technological edge,” and established five interdependent Warfare Development Imperatives, of which “layered resilience” is one [9]. Regarding layered resilience, NATO states “Fundamental to a strong defensive alliance is the ability to withstand a shock and fight-on. NATO’s Allies must ensure that weak points, both military and civilian, are reinforced and are sustainable in challenging situations over extended periods of time. This includes essential tools like supply lines and communications, but also that societies are resilient against disinformation” [9]. From both the perspectives of Sweden and NATO it is clear that functioning logistics and robust supply chains, including associated infrastructure, are fundamental components of societal resilience and layered resilience. The focus of this paper is on resilient defence supply chains, which constitute an essential subset of layered resilience.

From a Swedish military logistics perspective, the current paradigm shift involves transforming the lean and efficient logistics system designed to support expeditionary forces on international operations, to an agile system that is responsive and resilient enough to meet the new operational requirements associated with territorial defence [1]. The application for NATO membership further accentuates the importance of this transformation. To identify affordable solutions, Swedish defence authorities, including the SWE AF, the Swedish Defence Materiel Administration (FMV), the Swedish Defence Research Agency (FOI), and the Swedish Defence University (SEDU), have initiated several research and development projects over the past few years. Some of these projects have also involved the defence industry in Sweden.

This paper reports on results from two studies of the Swedish defence supply chain, henceforth referred to as Study 1 and Study 2, which the SWE AF commissioned. Study 1, conducted between 2017 and 2020, addressed segmentation and differentiation in defence supply chain design, used literature reviews, seminars, workshops, desk top exercises, focus groups and a modified Delphi technique to develop a dynamic purchasing portfolio for defence procurement. The research resulted in the development of a portfolio model for segmentation of military supplies [10], a set of eight differentiation strategies for defence supply chain design, [11] and a methodology for matching suitable differentiation strategies with supply segments [12]. While the study discussed resilience as a component of these supply chain strategies, it was not explicitly the focus of the research. The study also resulted in previously unpublished methodological implications regarding the application of a modified Delphi technique to enhance research rigour, which this paper presents.

Because of the implications for supply chain design of several disruptive events in global supply chains over the past few years, including the Covid-19 pandemic and the Russian war in Ukraine, Study 2 is currently focusing on resilience in defence supply chains. As a first step, this study, which commenced in 2022 and will continue until 2025, involves an extensive review of the academic literature on resilience in commercial supply chains and official documents from different nations and organisations, such as NATO, on other aspects of resilience for defence supply chains. The current Swedish Defence Bill and the Swedish application for membership in NATO emphasise the importance of research into resilient defence supply chains. The original intent was to conduct a Delphi study, based on the findings of the literature review and lessons learned from Study 1, during 2022. However, because of the pandemic and the war in Ukraine, Study 2 has had to postpone the Delphi study. Instead, the empirical part of the study thus far consists of a survey distributed to the participants in two other studies, one conducted by the SWE AF, and the other by SEDU. This paper reports on the findings of this survey.

The system in focus in both Study 1 and Study 2 is the Swedish defence supply network, with global extensions, which is an example of a socio-technical system where human participation and interaction are significant aspects. The research in the concluded Study 1 had, and in the ongoing Study 2 has, the ambition to involve practitioners from all echelons in the Swedish supply network in the research. The reason for this is twofold. First, to ensure that the results are of practical use to the defence authorities and the defence industry. Second, to enlighten the participants regarding theoretical developments in purchasing and supply chain management. This means that a qualitative research strategy is the most appropriate. The research in the two studies has used a mixed-methodology approach, with techniques such as surveys, workshops, desktop exercises, focus groups and a modified Delphi study. The purpose of the two studies is to identify feasible solutions for how the Swedish defence sector can redesign its supply network to meet the new challenges of a re-established Swedish Total Defence. The specific research questions addressed in this paper are:

- How can researchers modify the Delphi technique to enhance research rigour?
- How can authorities and companies increase defence supply chain resilience in peace, crises, and war?

To answer the first question, the results from a completed study, Study 1, will be discussed. The underlying hypothesis that Study 1 tested was that two parallel Delphi panels would enhance research rigour. Researchers have occasionally used parallel panels in previous studies. However, this study also formulated statements from different perspectives to the two panels. If they still came to the same results, this would reinforce the rigour of the method. As discussed in Section 4.0, although the findings of Study 1 are inconclusive, they point out that a modified design may lead to increased rigour, reveal unexpected results such as bipolarity, and avoid forced consensus.

To address the second question, the preliminary results from an ongoing study, Study 2, will be used. The hypotheses in Study 2 were a) that authorities and companies would arrive at different results, and b) that both authorities and companies would prioritise different strategies for supply chain resilience in peace, crises, and war. The preliminary findings from Study 2 indicate that prioritisations regarding the selection of supply chain resilience strategies in defence supply chains, such as multiple sourcing, pre-storage, and prepositioning, may have similarities with prioritisations in commercial supply chains.

The remainder of the paper is organised as follows. First, Section 2.0 presents theoretical perspectives on supply chain resilience. Section 3.0 describes the research methodology. Section 4.0 summarises and discusses the findings. Finally, Section 5.0 presents the conclusions and suggestions for further research.

## **2.0 SUPPLY CHAIN RESILIENCE**

Supply chain resilience is a developing field of knowledge, which does not have an undisputed definition, uncontested terminology, or a stringent use of concepts and constructs. In the following sections, a selection of terms, concepts, and constructs to describe the area of supply chain resilience will be addressed.

### **2.1 Background**

The first academic papers on supply chain resilience appeared in 2003 and 2004, [13] and the past few years have seen a dramatic increase in published papers on the topic [14]. This development is largely due to the globalisation of supply chains, which has made supply chains more exposed to disruptions [15]. Catastrophic events, such as terrorist attacks, tsunamis, and hurricanes have motivated supply chain researchers and practitioners to consider disruptions and their effects on supply chain design [16], which some researchers consider one of the most crucial planning problems in supply chain management [17]. A general categorisation divides supply chain risks into disruption risks and operational risks. Researchers typically define disruption risks as unplanned events that restrict a supply chain system, resulting from fabricated or natural disasters.

After almost twenty years, a substantial amount of research on supply chain resilience [13], [18] has been published, as well as several structured literature reviews [17], [19]. This literature shows that there is a lack of consensus regarding a well-grounded definition [16] and that there is a lack of clarity in relationships between supply chain resilience and its constructs [18]. The contributions of these structured literature reviews are several. They have identified three major constructs used to define supply chain resilience: phases of resilience, resilience strategies, and the capabilities needed to be resilient [18]; and that there is a shift from resilience definitions and principles to resilience measurement in the literature [13]. Others have defined the four phases of supply chain resilience: anticipation, resistance, recovery, and response [16]; and that supply chain flexibility, redundancy, collaboration, and agility are the supply chains resilience strategies most frequently referred to in the literature [20].

### 2.2 Definitions

The major objective of supply chain resilience is to strengthen the capability of the supply chain to withstand disruptions and recover quickly with minimal cost and effort [21]. The wide variety of definitions of supply chain resilience in the literature indicate a lack of consensus [13]. However, many of the definitions emphasise that the capability of a supply chain to respond, recover, and return to normal operations after a disruption is an essential factor of resilience [17]. A systematic literature review summarises the various definitions and states that researchers mainly define supply chain resilience as an ability, but also capability [13], but several reviews observe that a clear definition of supply chain resilience is non-existent [13], [15], [20], [21]. Some of these reviews note that definitions that are more recent are more complex and complete [15]. Rather than engaging in numerous examples, this paper simply uses one of the many recent proposals for a comprehensive definition of supply chain resilience:

*A resilient supply chain should be able to prepare, respond and recover from disturbances and afterwards maintain a positive steady state operation in an acceptable cost and time [15].*

### 2.3 Phases

Early definitions in supply chain resilience focused on response (during-disruption phase) and recovery (post-disruption phase), but over time, the narrow scope expanded to include elements of resilience-preparation and growth [18]. More recent contributions highlight preparation (pre-disruption phase) for unexpected events [22] and anticipation [23]. Similarly, the idea of seeking growth in the post-disruption phase is echoed in themes such as grow/growth in other more recent definitions [20]. This paper subscribes to the idea that there is a pre-disruption phase, a during-disruption phase, and a post-disruption phase, which all require different types of strategies to enhance supply chain resilience.

### 2.4 Strategies

Researchers have proposed several strategies to manage disruptions [17]. Many researchers particularly acknowledge the effectiveness of strategies such as flexibility, agility, collaboration, and redundancy [23], [24], [25]. There are numerous definitions of these four strategies in the literature, as well as many discussions regarding how they relate to each other and supply chain resilience. This paper uses the following definitions [19]:

- Flexibility is the ability “to respond to long-term or fundamental changes in the supply chain and market environment by adjusting the configuration of the supply chain.”
- Agility is the ability “to efficiently change operating states as a response to environmental uncertainty or volatile market conditions.”
- Collaboration is the ability “to work efficiently with other entities for mutual benefit in areas such as forecasting, postponement, and risk sharing.”

- Redundancy “involves the strategic and selective use of spare capacity and inventory that can be invoked to cope with a crisis, such as demand surges or supply shortages.”

Corresponding to the three phases of disruptions, some researchers categorise these strategies as proactive, concurrent, and reactive strategies [18], whereas others use only two categories, proactive or reactive [20]. The two types of strategies that are primarily discussed in the literature are mitigation strategies (proactive strategies) and contingency strategies (reactive strategies) [17]. For mitigation strategies, supply chain designers take preventive actions and pay their costs in advance, regardless of whether there is a disruption, whereas for contingency strategies, the supply chain actors take action only when a disruption occurs [25]. Researchers also refer to proactive and reactive strategies as resistance and recovery, respectively, in the literature [26]. Some researchers equate mitigation strategies with redundancy strategies, and contingency strategies with flexibility strategies [25]. Consequently, redundancy strategies invoke pre-disruption investment, which makes them less attractive for managers, whereas flexibility strategies incur costs only in the event of a disruption [25]. Some researchers consider proactive strategies, based on absorptive capacities, to be the first line of defence against disruptions [21], and reactive strategies, with adaptive and restorative capacities, as the second and third lines of defence [17].

There is no consensus in the literature regarding when practitioners should use which strategy, or their relative effectiveness. Some researchers support flexibility over redundancy, whereas others argue that redundant resources, such as safety stock and emergency backup suppliers, are primary solutions for enhancing supply chain responsiveness [16]. To resist disruptions in the pre-disruption phase, supply chains can use strategies such as redundancy – for example, high safety stock and additional production capacity, and flexibility – for example, alternative suppliers for sourcing and alternative transportation depots and modes for delivery [27]. During recovery in the during-disruption phase, the supply chain can utilise some of the same strategies as in the pre-disruption phase, for example, backup suppliers for sourcing, the buffer stock for satisfying customer orders, and redundant capacity for continuing the production [27]. The most common approach among companies to address disruptions is increased safety stock, dual or multi-sourcing, and better forecasting [14].

In a recent systematic literature review, the following strategies (tactics) have been found important to address disruptions [19]: supplier, logistics, sourcing, operational, process, capacity, manufacturing and supply base flexibility; collaboration; multiple sourcing; repositioning of inventories; backup suppliers; fortification; protection; emergency inventory; trust; information sharing; incentive alignment; visibility; resource mobility; capacity and workforce agility; and regionalisation. Another recent systematic literature review identified an alternative set [17] of approaches that include multiple sourcing; safety stock; repositioning of inventories; facility/supplier fortification; low-node density, complexity, and criticality; facility redundancy; lateral trans-shipment; multiple allocation of customers and facilities; alternative bill of materials; demand coverage; facility dispersion; flexible capacity at facilities; reassigning of customers; and expansion of facility capacity. Of these, safety stock and multiple sourcing are the most preferred in the literature, followed by facility/supplier fortification, node density, complexity and criticality, facility redundancy, lateral trans-shipment, and multiple allocations of customers and facilities [17].

## **3.0 RESEARCH METHODOLOGY**

### **3.1 Study 1 – Segmentation and Differentiation in Defence Supply Chain Design**

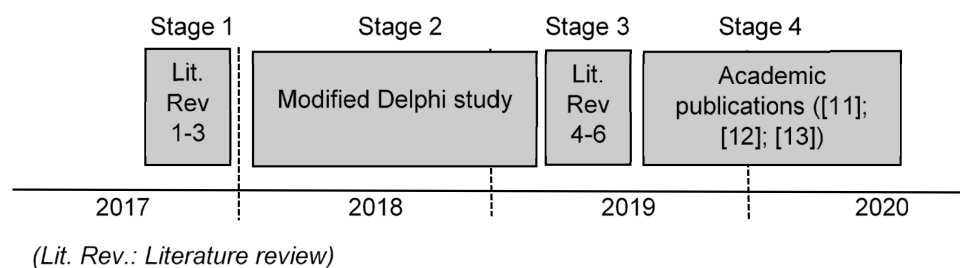
The Delphi technique is appropriate for generating collective knowledge and agreement on subjects for which expert opinions are the only source of available information [28], for research that deals with ambiguity and unsatisfactory knowledge [29], and when judgmental information is vital [30]. With the Delphi technique, researchers can elicit the insights of experts, while avoiding negative effects, such as biases, strong personalities, defensive attitudes, and disagreements, accompanying other methods [31]. Since expert opinions



are the primary source of information regarding the current Swedish defence supply chain, judgmental information is vital, and since the Delphi technique can avoid the negative effects of other qualitative methods [31], the study selected a modified Delphi technique as its primary vehicle for data collection.

### 3.1.1 Overview of the Research Process in Study 1

Study 1 consisted of four distinct stages (Figure 1). The first stage commenced with three reviews of the academic literature regarding military logistics and defence supply chains, segmentation models and differentiation strategies in purchasing and supply chain management, and recent developments in the Delphi technique. The second stage of the research process, the Delphi study, consisted of three phases. In Phase 1, the researchers designed the modified, conventional Delphi study. In Phase 2, the study collected data in three Delphi rounds, analysed the data, and began model development. In Phase 3, the study concluded model development, addressed unresolved issues from the Delphi rounds, and collected additional data and validated findings in two workshops.



**Figure 1: Overview of the research process in Study 1.**

In Stage 3, three additional literature reviews were conducted. The results from Stage 2 required a review of tactical levers in purchasing portfolio models. The final literature reviews addressed how rigour in Delphi studies should be addressed in theory, and how researchers address it in practice in the logistics and supply chain management literature. As part of the model validation, Stage 3 also included two desktop exercises in which practitioners could run through the proposed model and methodology in two, real-life procurement examples. The final stage involved dissemination of the research findings and resulted in three academic publications [10], [11], [12]. The previously unpublished findings of the research include the results of using a modified Delphi technique in the study, which this paper presents.

### 3.1.2 The Delphi Technique

The RAND Corporation developed the Delphi method (or technique) in the 1950s, in project DELPHI, to “obtain the most reliable consensus of opinion of a group of experts through a series of intensive questionnaires interspersed with controlled opinion feedback” [32]. The Delphi method is a systematic, iterative process, which allows anonymous interaction between panel experts [30]. It includes three activities: gather the opinion of a group of experts, synthesise and statistically summarise these opinions, and provide feedback to the participants. Researchers primarily use the method when judgmental information is essential [30]. It is particularly advantageous in reducing uncertainty by using practitioners and experts in the panels, and enlightening organisations on important and current issues [33].

Many academics have severely criticised the Delphi technique since its inception. The most unadorned critique came from within RAND itself, when a researcher criticised the method for being scientifically suspect and for its questionable application [34]. Following the critique concerning scientific rigour, there is a longstanding academic debate regarding which paradigm Delphi techniques belong to, positivism or interpretivism [35], or both. Closely related to this debate is the issue of establishing rigour [36], where advocates of

correspondence from quantitative research stand against supporters of trustworthiness from qualitative research [35]. Following the critique regarding practical issues, the Delphi technique continue to be criticised for how researchers use it in practice [30], [35]. Literature reviews have summarised the critique, identifying methodological inadequacies, unfortunate choice of experts, unsystematic execution, and ambiguous questionnaire designs [37]. To address the critique regarding potential misuse, several authors [30], [33], [38] have proposed guidelines regarding how to conduct rigorous Delphi studies. In a special issue on the Delphi technique in *Technological Forecasting & Social Change*, the guest editors summarised the many contributed recommendations for enhancing the use of the method under the following labels: panellist recruitment and attrition/retention, panel heterogeneity, information exchange, and question formulation [39]. Consequently, there is no shortage of generic guidelines and specific recommendations. However, they are not exhaustive, and they are occasionally contradictory. The guest editors summarise the situation, saying “There is still a lack of good empirical studies that provide more rigorous answers to the ‘how to’ questions” [39].

To ensure rigour, researchers must thoughtfully consider design issues, and justify the design [33]. Other researchers state “There is no evidence of the reliability of the Delphi method” and ask the rhetorical question “if the same information were given to two or more panels, would the same results be obtained?” [38], or observe “Clearly, there is incomplete knowledge with regards to establishing the rigour of the Delphi” and “further research is required to test the accuracy of the method” [35].

### **3.1.3 Design of the Modified Delphi Study**

Study 1 used a modified, conventional Delphi study in line with recommendations in the literature [33]. The study used four modifications to the conventional Delphi method:

- 1) Two Delphi panels;
- 2) A predetermined number of rounds;
- 3) A seeded list, based on open issues in the literature, as statements in the first round; and
- 4) Two concluding workshops to review and extend findings [40].

These are all well-documented modifications of the design. The modification with two panels is not common, but researchers have used it previously [41]. The novelty of this study is the combination of the four, and that the study presented the panels with statements from different perspectives to enhance the rigour.

For this study, knowledgeable practitioners and researchers from the Swedish defence authorities were invited: thirty-three from the Swedish Armed Forces (SWE AF), eight from the Swedish Defence Materiel Administration (FMV), and two each from the Swedish Defence Research Agency (FOI) and the Swedish Defence University (SEDU). When prior knowledge of the expertise of individuals was available, invitations went directly to these experts. In most cases, managers of relevant organisational units within the Swedish defence authorities were invited and asked to allocate experts to the study. The invited practitioners from the SWE AF included the strategic, operational, and tactical perspectives on military logistics, while the practitioners from FMV represented the military, technical, commercial, and legal perspectives on defence procurement. The invited researchers from FOI have long experience with doing research on logistics and procurement in close cooperation with the defence authorities. The invited researchers from SEDU are officers, who combine extensive practical experience with a research perspective. The final panel consisted of twenty experts, consisting of twelve from the SWE AF, four from FMV, two from FOI, and two from SEDU. The study guaranteed anonymity and confidentiality, and that the panellists could leave the study at any point. The experts had no knowledge of the total number of participating experts, their identity, or of the two panels.

With twenty experts, the study had the opportunity to use a modified design, with two panels, for the following three reasons. First, this was an opportunity to enhance the validity of the results through increased research rigour. If the two panels independently came to the same results, this would reinforce the validity. Second, given the results of the literature review on purchasing portfolio models, which included divergent opinions

on design and application, it was difficult to formulate questions, or statements, that the panellists could answer using a Likert scale. The option to use extremes from the literature as extremes on Likert scales was not adopted, as with two panels, the study could formulate statements from different perspectives to the two panels, which made questionnaire design and subsequent analysis less ambiguous. If the two panels arrived at the same conclusions despite the different statements, this would reinforce the validity of the results. Third, academics have accused the conventional Delphi method of forcing consensus [36]. Two panels would mitigate this risk, especially considering that the study formulated statements from different perspectives. In this modified approach to the Delphi method the experts were assigned to the two panels randomly, with the restraint that the representation should be similar. The panels each had ten experts, consisting of six from the SWE AF, two from FMV, one from FOI, and one from SEDU. In the first panel, the response rates in the three rounds were 100%, 80% and 70%. In the second panel, the corresponding rates were 100%, 90% and 80%.

The study distributed an introduction package before the first round. It contained a description of the study and its background, and an overview of the academic literature on purchasing portfolio models, summarising the debate on application issues. In addition to a predetermined number of rounds and two Delphi panels, the statements in the first round were a seeded list, based on open issues in the literature. In line with the academic discussion on the application of purchasing portfolio models, five statements from different perspectives to the two panels (Table 1) were formulated. The panellists provided answers on a five-level Likert scale, ranging from “strongly disagree” to “strongly agree.” For each statement, they could justify their answers in free text. Abstaining panellists could motivate this choice in free text.

**Table 1: Open issues in the literature and statements put forward to the two Delphi Panels.**

Open Issues in the Literature	Statements put Forward to Panel 1	Statements put Forward to Panel 2
Prescriptive or catalyst for discussions?	A purchasing portfolio model should be prescriptive. For each segment, there should be clear, governing recommendations.	A purchasing portfolio model should be a catalyst for in-depth discussions among stakeholders.
Strict or pragmatic application?	Users should apply the recommendations in a purchasing portfolio model strictly. If segmentation has placed a supply in a particular segment, users should always apply the recommended strategies in that segment strictly.	Users should apply the recommendations in a purchasing portfolio model pragmatically. Regardless of position in the model, users can apply strategies from other segments if deemed appropriate.
Segment-generic or purchase-specific strategies?	Strategies should be segment-generic, developed exclusively for different segments.	Strategies should be purchase-specific, developed for individual purchases, regardless of segment.
Static or dynamic application regarding changes in the environment?	A purchasing portfolio model should be static. Users should not conduct a new segmentation because of changes in the environment.	A purchasing portfolio model should be dynamic. Users should conduct a new segmentation when the environment changes.
Static or dynamic application regarding repositioning?	A purchasing portfolio model should be static. Users should not attempt to change the segmentation to move to a more favourable position.	A purchasing portfolio model should be dynamic. Users should, immediately after segmentation, analyse any opportunities to move to a more favourable position.

For each round, the researchers analysed answers to determine whether to alter, delete or add statements. There were no insights that motivated changes in the first round. The study repeated the statements in the second round and provided the most frequent answers, the mean, and other panellists’ justifications and motivations.



The tendency to change answers between rounds was limited. The revisions reinforced the most frequent answers and reduced standard deviations. The researchers interpreted this as an indication that a third round on the same format would not provide any further insights, and accordingly made changes. The research purpose involved resolving issues regarding application of purchasing portfolio models. The study used the third round to elicit answers to these issues. Instead of a Likert scale, the study asked the panellists to answer “yes,” “no” or “I don’t know” on the statements from the first rounds. For most statements, round three led to consensus in both groups with slight majorities in some cases, and for one statement, the two panels reached diametrically opposed results (Table 2).

The purpose of the workshops was to reach clarity and, if possible, reach consensus regarding application rules. Before the workshops, the study distributed the results of the final Delphi round. The discussions during the workshops primarily focused on the statement where the two panels had reached very different results. The participants were able to interpret the surprising results and agree on application rules. The study used the output of the first workshop as input to the second, which allowed the participants to start discussions on a higher level of understanding.

## **3.2 Study 2 – Resilience in Defence Supply Chain Design**

### **3.2.1 Overview of Research Process in Study 2**

The original intent of Study 2 was to have a similar research process as Study 1 (Table 1). However, due to the pandemic and the Russian war in Ukraine, the study started with a different approach. The first step is an ongoing literature review regarding supply chain resilience in academic journals. Based on the preliminary results of this literature review, a survey was conducted, using subject matter experts in the Swedish defence authorities (the SWE AF study) and the defence industry in Sweden (the SEDU study).

### **3.2.2 A Survey on Enhancers of Supply Chain Resilience**

Even though Study 2 has yet to finalise the literature review, the opportunity to include questions regarding supply chain resilience in two other studies presented itself in February of 2022. The SWE AF and SEDU, respectively, conduct the two studies. The two studies address different aspects of redesigning the defence supply chain in light of the new focus on territorial defence. The studies agreed to conduct a joint survey on value co-creation in defence supply chains. After acceptance from the two studies, the author, who designed the survey, included supply chain resilience as part of the survey. The SWE AF study includes twenty subject matter experts from different defence authorities. Fifteen experts represent the operational and tactical levels, including representation from all services and all logistical functions, in the SWE AF. Two experts represent FOI. The study also includes one expert each from FMV, SEDU and the Swedish Fortifications Agency. The SEDU study has one expert each from FMV, FOI and SEDU. These three experts are also part of the SWE AF study. However, in addition to representation from the Swedish defence authorities, the SEDU study also has five participants from four defence industries in Sweden.

While the literature review in Study 2 is ongoing, the preliminary results can be used to aid the formulation of questions for the survey. Early contributors to the knowledge base on supply chain resilience identified flexibility and redundancy as important aspects of resilience [24]. More recently, a structured literature review established that flexibility, redundancy, collaboration, and agility are the most frequently declared elements of supply chain resilience in the literature [42]. In another structured literature review, the authors label flexibility, agility, collaboration, and redundancy as drivers, enhancers, or antecedents of supply chain resilience [19]. Each of these antecedents of supply chain resilience have numerous different tactics that supply chain designers can employ to enhance resilience. In addition, there is no consensus in the literature. As an example, researchers do not agree on how flexibility and agility relate to each other, and they are often used interchangeably [13].

Altogether, the variants of supply chain strategies are too plentiful to include in a survey if the study is going to be able to keep the response rate at an acceptable level. Furthermore, to use unclear terminology, such as flexibility and agility, would likely confuse the respondents. Consequently, it was decided against including both flexibility and agility, documented tactics for flexibility, redundancy, and collaboration, and used a pilot study and a focus group to identify a suitable subset of tactics to include in the survey. In addition to the tactics identified in the literature review on supply chain resilience, military-specific tactics identified in Study 1 were added [12]. Based on the pilot study and the comments from the focus group, rephrasing and clarification of some of the tactics took place. Moreover, it was decided to use the following subset of twenty-two different tactics:

- Contingency planning;
- Decentralisation of production;
- Flexible production capacity;
- Flexible storage capacity;
- Flexible transportation capacity;
- Multiple allocation of storage facilities;
- Multiple modes of transportation;
- Multiple sourcing;
- Overlapping operational capabilities;
- Repositioning of supplies (finished goods);
- Pre-storage of supplies (finished goods);
- Protection of production facilities;
- Protection of storage facilities;
- Protection of transportation;
- Redundancy in operational capabilities;
- Redundancy in production capacity;
- Redundancy in storage capacity;
- Redundancy in transportation capacity;
- Safety stock (materials, components, systems);
- Standardised supplies;
- Strengthened buyer-supplier relationships; and
- Substitute supplies.

The participants in the SWE AF and the SEDU studies received identical surveys. These two surveys were named differently, so that the answers could be analysed separately for each study and presented separately to the two studies. The survey asked the twenty respondents in the SWE AF study and the five defence industry representatives in the SEDU study to select from their point of view in the defence supply chain the three tactics that they thought are the most important to enhance supply chain resilience in peace, crises, and war. The survey also gave the respondents the option of abstaining from answering or selecting fewer than three tactics. Fifteen, or 75%, of the participants in the SWE AF study responded, while five, or 100%, of the industry representatives in the SEDU study provided answers to the questionnaire. The results of the survey were presented to the two study groups separately and interpretations and the implications of the results in these plenary sessions was also discussed. Also, in the SWE AF study, the results were discussed with the participants in two workshops.

## 4.0 FINDINGS AND DISCUSSION

### 4.1 Results from the Modified Delphi Study

During the workshops, the panellists reached consensus regarding all open issues. However, the path to consensus was dissimilar. Table 2 illustrates the degree of consensus and dissent through the three Delphi rounds. For the most part, the different paths to consensus illustrate the equifinality of the progress in the two panels. However, for one of the open issues, the process ended in bipolarity.

For the first open issue, if purchasing portfolio models should be prescriptive or serve as catalysts for discussions, the two panels reached diametrically opposed results in the first round. By round three, both panels reached consensus, where one panel decided that the purchasing portfolio model should be prescriptive, and the other that the purchasing portfolio model should serve as a catalyst for discussions among stakeholders. During the workshops, the panellists decided that a purchasing portfolio model could be both prescriptive and serve as a catalyst for in-depth discussions. The purchasing portfolio model should be prescriptive for routine supplies, where the market has guaranteed or high ability to deliver supplies on time, while absence of such supplies would have minor or non-existent limitations in the Armed Forces operational capability. For all other decision-situations, the model should serve as a catalyst for in-depth discussions among stakeholders. For all other open issues, the two panels reached similar results, even if the paths were slightly different. The panels both concluded that the application should be pragmatic, which means that the methodology should allow the use of strategies from other segments. The panellists decided that they preferred segment-generic strategies to purchase-specific ones. The panels reached the conclusion that application should be dynamic regarding environmental changes, and that the methodology consequently should require new segmentation when circumstances in the environment change. Finally, the panels also agreed that the methodology should be dynamic regarding repositioning and allow immediate actions to reposition to a more favourable segment.

Researchers have stated “There is no evidence of the reliability of the Delphi method” and asked the rhetorical question “if the same information were given to two or more panels, would the same results be obtained?” [36], whereas others have observed, “Further research is required to test the accuracy of the method” [34]. This study used two Delphi panels, with a similar distribution of experts in them, gave them the same information, and presented them with statements from different perspectives. The expectation was that the two panels would arrive at the same conclusions, thereby enhancing rigour. The panellists addressed five open issues regarding purchasing portfolio model application. Based on open issues in the academic discussion on purchasing portfolio model application, the study formulated statements from different perspectives, so that agreement with a statement in one panel would correspond to disagreement in the other. As illustrated in Table 2, following slightly different paths, the two panels arrived at similar results for four of the open issues. However, for the first issue, they arrived at diametrically opposed results, where one panel decided that the purchasing portfolio model should be prescriptive, whereas the other concluded that the purchasing portfolio model should serve as a catalyst for discussions among stakeholders. This result was unexpected, and had the research design not included concluding workshops, the end result of the study would have been bipolar. However, during the concluding workshops, the participants discussed the contradictory results at length, until arriving at the consensus conclusion that a purchasing portfolio model can be both prescriptive and a catalyst for discussions. The result of the study is that the purchasing portfolio model should be prescriptive for routine segments and serve as a catalyst for discussions for all other segments. The question is why the study produced this result. Is it a consequence of the two panels, the different formulations of the statements, the workshops, or a combination? Another question is if a conventional study, with one Delphi panel and no workshops, could have reached a similar result. A third question is if a one-panel study with a workshop could have produced similar results.



**Table 2: Results from Delphi rounds and workshops.**

Open issues in the literature	DR 1	DR 2	DR 3	WS
Prescriptive? Catalyst?	DP 1: Y (Q) DP 2: Y (Q)	DP 1: Y (Q) DP 2: Y (Q)	DP 1: Y (C) DP 2: Y (C)	Prescriptive for routine segments and catalyst for discussion for others (C)
Strict? Pragmatic?	DP 1: B DP 2: Y (Q)	DP 1: B DP 2: Y (Q)	DP 1: N (M) DP 2: Y (c)	Pragmatic application (C)
Segment-generic? Purchase-specific?	DP 1: B DP 2: B	DP 1: B DP 2: B	DP 1: Y (M) DP 2: N (Q)	Segment-generic strategies (C)
Static? Dynamic? (environment)	DP 1: N (c) DP 2: Y (c)	DP 1: N (c) DP 2: Y (c)	DP 1: N (c) DP 2: Y (C)	Dynamic application (C) (environment)
Static? Dynamic? (repositioning)	DP 1: N (M) DP 2: Y (M)	DP 1: N (Q) DP 2: Y (Q)	DP 1: N (c) DP 2: Y (c)	Dynamic application (C) (repositioning)
<p><i>DR = Delphi round; WS = Workshop; DP = Delphi panel; Y = Yes, N = No, C = Consensus (100%), c = Near-consensus (&gt;85%), Q=Qualified majority (&gt;2/3), M=Majority (&gt;1/2), B=Bipolarity (Y ≈ N).</i></p> <p><i>The response rates in DP 1 for DR 1-3 were 100%, 80% and 70%, and in DP 2, 100%, 90% and 80%.</i></p> <p><i>Nota bene: agreement between the two panels occurs when one panel answers “Yes” and the other panel answers “No,” and vice versa, since the study presented the two panels with statements based on different perspectives. “Yes” from both panels regarding the first open issue is consequently disagreement between the two panels.</i></p>				

The study addressed the rhetorical question regarding two panels [34] and the provisional answer is “yes and no.” The study obtained the same results for four of the five open issues, thus reinforcing the validity of these results, but for the remaining issue, the two panels came to very different results. However, contrary to a widespread misconception, that consensus is always the objective in a Delphi study [22], [38]; bipolarity is also a possible result of a conventional Delphi study. It is accordingly possible that the study could have reached bipolarity after three rounds, also if it had used one panel, and used the extremes from the literature review as extremes on Likert scales in the questionnaire. Consequently, it is not possible to state that the two panels provided any other results than what a conventional study might have done. With a concluding workshop, a one-panel study could also have reached a similar consensus solution.

Poor questionnaire design has been a source of critique of Delphi studies [35]. In the questionnaires in Study 1, the seeds came from the academic debate on purchasing portfolio model application, where academics stand against each other regarding a number of issues. The study provided the panellists with the same background information, including both sides of the academic debates, but formulated the statements to the two panels from different perspectives. The study used piloting to ensure that the statements were unambiguous. Nevertheless, it is possible that the formulation of the statements forced the two panels to consensus [26], but in different directions. Some researchers suggest that studies can use workshops in Delphi studies to review and extend findings [25]. This study included workshops at the end of the study in its design for this purpose. During these workshops, the participants discussed the seemingly contradictory result of the Delphi rounds and were able to reach consensus. Without these workshops, it seems unlikely that the study would have produced the novel purchasing portfolio model, which is both prescriptive and a catalyst for discussions among stakeholders.

The study produced a novel purchasing portfolio model [1], [10], [11], [12], which the practitioners who participated in the study perceived as an innovation that will be of practical use in defence acquisition. A purchasing portfolio model consists of a segmentation model, tactical levers, differentiation strategies and guidance for management decisions. In this case, the segmentation model is a two-stage model based on three dimensions, a precursor, and a two-dimensional model, with four values for each dimension. The precursor represents the operational requirements of the Swedish Armed Forces, and the two-dimensional model represents the market’s ability to deliver supplies and limitations in the Swedish Armed Forces operational capability if the market does not deliver supplies on time. The researchers found it unlikely that the novel design would have been possible without the participation of experts in two different panels. As discussed above, it is possible that a conventional Delphi study could have reached a similar result after three rounds, with or without workshops. However, it seems unlikely that a conventional design, without the concluding workshops, could have produced the novel purchasing portfolio model. A prerequisite would have been if the researchers had presented the panellists with the option of developing a model that was both prescriptive and could serve as a catalyst for in-depth discussions. However, the literature on purchasing portfolio models did not provide this as a possible seed for the questionnaires.

#### 4.2 Results from the Survey on Supply Chain Resilience

Table 3 and Table 4 illustrate the percentage of respondents who included the tactic among the three they could select. As illustrated in Table 3 and Table 4, the replies from the respondents in the studies is inconclusive. Most results do not strongly indicate any preferences between the different tactics. However, a few results are exceptions. To some extent, the respondents from the defence authorities (the SWE AF study) and the defence industry (the SEDU study) agree that multiple sourcing is an important strategy, particularly in peace and crises. There is also an indication of agreement regarding the importance of pre-storage and prepositioning of supplies in crises and war. These results are in line with recent findings from the literature, which identify increased safety stock and multi-sourcing as two of the most commonly used tactics to address disruptions in commercial supply chains [39], [42].

**Table 3: Results from the survey on supply chain resilience.**

Tactic	Peace		Crisis		War	
	SWE AF study *	SEDU study **	SWE AF study *	SEDU study **	SWE AF study *	SEDU study **
Contingency planning	0.0	0.0	0.0	20.0	13.3	60.0
Decentralisation of production	0.0	0.0	0.0	0.0	0.0	0.0
Flexible production capacity	6.7	40.0	13.3	0.0	0.0	0.0
Flexible storage capacity	6.7	0.0	0.0	0.0	6.7	0.0
Flexible transportation capacity	20.0	20.0	20.0	0.0	6.7	0.0
Multiple allocation of storage facilities	6.7	20.0	6.7	20.0	33.3	0.0
Multiple modes of transportation	20.0	20.0	6.7	0.0	6.7	0.0
Multiple sourcing	53.3	60.0	33.3	60.0	20.0	20.0
No answer ***	6.7	0.0	0.0	0.0	0.0	0.0



Tactic	Peace		Crisis		War	
	SWE AF study *	SEDU study **	SWE AF study *	SEDU study **	SWE AF study *	SEDU study **
Overlapping operational capabilities	13.3	0.0	6.7	0.0	6.7	20.0
Prepositioning of supplies (finished goods)	20.0	0.0	40.0	20.0	53.3	20.0
<p>* Percentage of 15 respondents from the Swedish defence authorities who selected the tactic as one of the three most important;</p> <p>** Percentage of 5 respondents from the Swedish defence industry who selected the tactic as one of the three most important;</p> <p>*** One respondent selected only two most important tactics.</p>						

As mentioned before, the results from the survey were presented and discussed with the respondents in plenary sessions in both studies. Similarly, in the SWE AF study, the findings were also discussed in two workshops. The main results from the workshops were that the respondents found it difficult to select only three tactics, and that by addressing only a few aspects of resilience in the defence supply chain, the weak points would move to other parts of the network.

**Table 4: Results from the survey on supply chain resilience (cont.).**

Tactic	Peace		Crisis		War	
	SWE AF study *	SEDU study **	SWE AF study *	SEDU study **	SWE AF study *	SEDU study **
Pre-storage of supplies (finished goods)	33.3	20.0	66.7	60.0	40.0	40.0
Protection of production facilities	0.0	0.0	0.0	0.0	0.0	20.0
Protection of storage facilities	6.7	0.0	13.3	20.0	0.0	0.0
Protection of transportation	0.0	0.0	6.7	0.0	20.0	20.0
Redundancy in operational capabilities	0.0	0.0	6.7	20.0	13.3	20.0
Redundancy in production capacity	13.3	20.0	6.7	40.0	13.3	20.0
Redundancy in storage capacity	6.7	0.0	20.0	0.0	26.7	20.0
Redundancy in transportation capacity	6.7	0.0	20.0	0.0	20.0	0.0
Safety stock (materials. Components. Systems)	20.0	20.0	20.0	20.0	13.3	20.0
Standardised supplies	26.7	20.0	6.7	0.0	6.7	0.0

Tactic	Peace		Crisis		War	
	SWE AF study *	SEDU study **	SWE AF study *	SEDU study **	SWE AF study *	SEDU study **
Strengthened buyer-supplier relationships	20.0	60.0	0.0	20.0	0.0	20.0
Substitute supplies	13.3	0.0	6.7	0.0	0.0	0.0
<p>* Percentage of 15 respondents from the Swedish defence authorities who selected the tactic as one of the three most important;</p> <p>** Percentage of 5 respondents from the Swedish defence industry who selected the tactic as one of the three most important;</p> <p>*** One respondent selected only two most important tactics.</p>						

The results from the survey, the plenary sessions, and the workshops advocate a holistic view on supply chain resilience, where researchers and practitioners address the entire network simultaneously. Another key take-away from the discussions in the SWE AF study was that, depending on their position in the supply chain, the respondents might not have a full understanding of the upstream part of the supply chain, particularly not the dependence on external suppliers. Their limited perspectives influenced their selections of the three most important tactics significantly. This may also explain why few respondents in the SWE AF study selected strengthened buyer-supplier relationships as one of the three most important tactics, while three out of the five representatives of the defence industry considered this tactic important in peace.

## 5.0 CONCLUSIONS

### 5.1 The Modified Delphi Study

The first research question that this paper addresses is “How can researchers modify the Delphi technique to enhance research rigour?” The underlying hypothesis is that two parallel Delphi panels enhance research rigour. If two panels reach the same results, the findings are more trustworthy, particularly if researchers present the two panels with statements from different perspectives. This study used four modifications to the conventional Delphi method:

- 1) Two Delphi panels;
- 2) A predetermined number of rounds;
- 3) A seeded list, based on open issues in the literature, as statements in the first round; and
- 4) Two concluding workshops to review and extend findings.

Based on the open issues in the literature, the study formulated statements to the two panels from different perspectives, which is a novel modification to the technique.

The findings of Study 1 are inconclusive, since we do not know if other designs would have come to similar results. However, the findings indicate that a modified Delphi design may lead to increased rigour, but also to unexpected results. The analysis illustrates the possibilities of modified designs. Conventional designs may lead to forced consensus [36] and thus miss results that are more complex, such as bipolarity. Two Delphi panels may thus enhance rigour, but also more easily reveal bipolarity and avoid forced consensus. Providing statements from different perspectives to the two panels may also have been a factor that enabled the study to arrive at surprising results. Furthermore, concluding workshops proved to be instrumental in the study, thus

confirming previous suggestions in the literature [40]. The workshops helped the researchers to interpret the findings and produce a novel purchasing portfolio model [1], [10], [11], [12], which the participating practitioners perceive as an innovation that will be of practical use in defence acquisition. The conclusion is that, at least in some cases, the design of a Delphi study will have an impact on which results the study produces. If the design was indeed responsible for the innovative results of the study, the methodological findings are also inconclusive, since we do not know which modification that was the main contributing factor, or if it was the combination of two or three modifications that led to the results.

## **5.2 Survey on Supply Chain Resilience**

The second research question that this paper addresses is “How can authorities and companies increase defence supply chain resilience in peace, crises, and war?” The hypotheses in Study 2 were:

- a) that authorities and companies would arrive at different results; and
- b) that both authorities and companies would prioritise different strategies for supply chain resilience in peace, crises, and war.

There is some evidence to support both hypotheses, but the results are inconclusive. There are indications that there are differences between the prioritisations between the defence authorities and the defence industry, and that they make different priorities in peace, crises, and war. However, the fragmented results do not present a solid foundation, so that any hard conclusions based on the survey cannot be drawn. This is hardly surprising, since the survey was an enforced substitute for a Delphi study.

Even though the findings are preliminary, there are indications that prioritisations regarding selection of supply chain resilience strategies in defence supply chains may have similarities with prioritisations in commercial supply chains. The preliminary findings of Study 2 indicate that both defence authorities and the defence industry consider multiple sourcing, pre-storage, and prepositioning important strategies to enhance resilience in defence supply chains. These findings are in line with previous research, which has demonstrated that increased safety-stock and multi-sourcing are two of the most commonly used strategies to address disruptions in commercial supply chains [39], [42]. Nevertheless, the varying views of the respondents was a bit startling. To some extent, this can be attributed to the respondents’ positions in the supply chain, where some respondents are unaware of the defence supply chain’s dependence on commercial supply chains. These preliminary findings should be regarded as an indication that supply chain resilience requires a holistic approach. A multi-echelon approach is required, and the solutions are likely to entail combinations of several strategies.

## **5.3 Further Research**

This paper presents the results from a Delphi study in which the researchers modified the design to enhance rigour. The study indicates that research design may influence the results of Delphi studies. Furthermore, the study suggests that there may be limitations to conventional designs, and possibilities with modified designs. In future research, it would be interesting to investigate if these preliminary results are generalisable, and if so, if the results hold under any particular conditions. Study 1 used four modifications simultaneously, which in combination influenced the results of the study. Moreover, it would be interesting to analyse these modifications individually, to establish the contribution of each. In particular, it would be interesting to see more studies that combine two panels with questions or statements from different perspectives, to explore this modification further. It would also be of interest to see a study with four panels, where one panel is a traditional panel, one is a traditional panel with a concluding workshop, and two panels receive statements from different perspectives, to investigate if they arrive at similar results.

This paper also reports on the results of a survey on resilience in defence supply chains. This survey was intended to provide the first steps towards layered resilience. However, the survey turned out to be a poor substitute for a Delphi study. As a next step, this study will conduct a more comprehensive study of the Swedish defence sector.

Once there are any conclusive results from this study, further research, in other contexts and with other methodologies, is required to generalise those results. Nevertheless, the preliminary findings already indicate a resemblance between prioritisations of suitable supply chain strategies in defence and commercial supply chains. In future research, it would be interesting to explore such similarities and differences further. Moreover, it would also be of interest to use war-gaming, scenario techniques and modelling and simulation, to explore which strategies and tactics are most suitable to enhance resilience in defence supply chains, since these methodologies enable a holistic perspective on the entire defence supply network.

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