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SUPPLY CHAIN VIABILITY IN THE CONTEXT OF THE RUSSO-UKRAINIAN WAR: AN EMPIRICAL STUDY OF GERMAN CAR MANUFACTURERS

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Abstract:

This thesis studied Supply Chain Viability (SCV) of German car manufacturers in the context of the Russo-Ukrainian war. Expert interviews and surveys were used to analyze the impacts of the war as well as dimensions and capabilities of SCV. As a result, four impact categories, one additional dimension and three additional capabilities were identified which allowed for an updated SCV framework to the studied context, consisting of three SCV dimensions and eight SCV capabilities. Additionally, capabilities were ranked to perceived importance for SCV and compared from before the war to now in order to add quantification missing in previous research.

Keywords:

Supply chain viability, supply chain resilience, supply chain management, Russo-Ukrainian war, procurement, logistics, disruptions, Germany, car manufacturers, automotive, adaptation

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Acronyms

ASC	Automotive Supply Chain
ISN	Intertwined Supply Network
OEM	Original Equipment Manufacturer
SC	Supply Chain
SCM	Supply Chain Management
SCRES	Supply Chain Resilience
SCV	Supply Chain Viability

1 Introduction

After the COVID-19 pandemic and semiconductor shortages, the Russo-Ukrainian war caused another crisis in German automotive supply chains (ASC). With critical parts being sourced from Ukraine, many German car manufacturers experienced production halts due to sudden disruptions in the upstream supply chain (SC) (Boston, 2022). Besides the disastrous humanitarian consequences of that war, the viability of SCs was/is at risk and lead/leads to major disruptions which cause great financial damage for all companies involved.

The context of the ongoing war was chosen because of its recency and therefore little research being finished about it. In combination with that, supply chain viability (SCV) is a relatively new research field which is mostly studied through the pandemic and needs to be explored further in other contexts (Chervenkova & Ivanov, 2023;). The German automotive industry is studied for three reasons: First, it was affected by the war through SC disruptions and trade embargoes. Second, the automotive industry in general is known for being a sector leader with best practices in dealing with problems in SCs (Belhadi et al., 2021). And third, it is a major driver of the German economy, with crucial parts of its success built on its complex SCs. In 2022, 786k Germans were employed by the automotive industry (Statista, 2023). In the same year 411 billion € (≈ 11% GDP) in revenue was generated by the industry, highlighting its importance for the country (BMWK, n.d.). This study will analyze the SCV of German car manufacturers (e.g., Volkswagen, Mercedes, Audi, BMW, Porsche, Daimler Truck, Mercedes Benz Vans) and answer the following research questions:

RQ1: What was/is the impact on supply chains?

RQ2: What adaptation strategies were/are used for SC viability?

RQ3: Which SC viability capabilities are best/least developed, and which are considered most important for SCV?

RQ4: How have capabilities developed?

2 Literature review

2.1 Supply chains and supply chain management

To begin with, the terms supply chain and supply chain management (SCM) will be introduced and explained in order to form a theoretical foundation for the study. For both terms, there are various definitions in the literature. In the supply chain, according to Beamon (1998), an orderly manufacturing process transforms raw materials into final products that are then transported to the end customer. Mentzer et al. (2001) provide another explanation, according to which an SC can be considered as a group of at least three organizations or individuals that are directly involved in the upstream and downstream flows of products, services, information and/or finances from a source to a customer. In recent years, SCs have become more complex to benefit from economic globalization. As a result, many activities are outsourced and SC consist of more tiers which often are located in other countries or on other continents (Li et al., 2023).

Looking at SCM, the term is most commonly used in research in combination with the globalization of production and procurement and the resulting requirements to profitably manage worldwide flows of goods. In this context, the market focuses not only on the goods, but also on the supply chains providing them (Trkman et al. 2005). Werner (2017, p. 6) builds on concepts from Stevens (1989) and provides a comprehensive definition: SCM spans from the source of supply to the point of consumption and includes material, information, and money flows along the entire value chain (supply, disposal, recycling). Additionally, a social aspect can be incorporated by considering the relationships between the SC actors (Werner, 2017, p. 6). In competition, it is increasingly important to deliver goods at the desired time and quality to meet the important benchmark of customer satisfaction. This makes the management of SC actors a crucial role (Trkman et al. 2005). Moreover, effective management is needed to ensure flexibility of SCs in the face of uncertainties and fluctuations (Janvier-James 2012).

2.2 Automotive supply chains

Building on the definitions of SCs and SCM, automotive supply chains are characterized by globalization of production and procurement, multiple organizations taking part in the upstream and downstream flows of products, services, information and/or finances from raw materials to the car buyer (Mentzer et al., 2001). These lean ASCs have resulted in high efficiency and cost savings during predictable and stable conditions (Křenková et al., 2023). However, they entail the risk of disruption in the event of unstable conditions (Krykavskyy et al., 2023). In an ASC, many steps are outsourced to other companies, e.g., suppliers. The typical ASC has a multi-tier upstream structure from raw materials to the in-house manufacturing assembly process at the original equipment manufacturer (OEM). Yet, the visibility of the OEM into the upstream ASC often ends at the Tier-1 supplier (Reddy et al., 2021). To illustrate this, the OEM e.g., has an overview of the supplier that delivers important wiring harnesses (cables that connect all electronics in a car), but has no insight beyond that into the intermediate parts and raw materials in the tiers beyond the Tier-1 level.

This thesis only focuses on ASCs from the source of supply to the production at the OEM since many suppliers of German OEMs are located in Eastern Europe, like Ukraine. Therefore, the impacts of the Russo-Ukrainian war on ASCs mainly appear(ed) in sourcing. Moreover, sales and vehicle distribution (i.e., downstream) can be considered different disciplines with other characteristics (Křenková et al., 2023).

2.3 Impacts and challenges of the war on SCs of German car manufacturers

As mentioned in the previous chapter, ASCs were impacted by the war in Ukraine and caused/cause disruptions in upstream SCs and vehicle production. These impacts hit ASCs that were already affected by the Covid-19 pandemic and semiconductor shortages (Krykavskyy et al., 2023). In the following, categories should be used to present the impacts on of the war on

ASCs of German OEMs (see Table 1). Most impacts result in "(1) a shortage of raw materials and components, following the reduction in the industrial capacity of many suppliers; and (2) logistical restrictions on product transport […]" (Paché, 2022). (3) as a third category, negative financial impact should be added due to financial flows being part of a SC and the necessity of good financials to keep operations running, especially on the supplier level. It is important to notice that the examples of each category often have related backgrounds.

Table 1 War impacts on German Automitive Supply Chains

Category	Impact and challenge examples
(1) Raw material and components shortage, followed by reduced industrial capacity of suppliers	• Lack of raw material from Russia such as palladium and nickel needed to produce car components like batteries and catalytic converters (Guénette, 2022) • Additional pressure on semiconductor production due to lack of materials used in their production processes (Min & Zhou, 2002; Teer & Bertolini, 2022) • Shutdown of components production, e.g., cable harnesses that are produced by a large share in Ukraine and are crucial for car manufacturing (Campbell & Miller, 2022; Křenková et al., 2023) • Reduced and paused production at German OEMs (Křenková et al., 2023) • Relocation of component production and material sourcing from other regions (Paché, 2022)
(2) logistical restrictions on product transport	• Transportation delays and disruptions due to lack of Ukrainian truck drivers who went back to their families or joined the military (Paché, 2022) • Military damage of logistical infrastructure, causing delays and SC disruptions (Paché, 2022; Krykavskyy et al., 2023) • Blockage of SCs connected to Russia (Korn & Stemmler, 2022)
(3) negative financial impact	• Increased prices of raw materials, components and services (Paché, 2022) • Increased prices for energy (Křenková et al., 2023) • Increased cost on logistics due to alternative routing (Korn & Stemmler, 2022) • Lost sales of OEMs due to reduced or disrupted production capacities (Křenková et al., 2023) • Blocked payment transfers to and from Russia (Křenková et al., 2023)

A study from May 2022 on material shortages demonstrates that industry top managers were more concerned amid the war than during the Covid-19 pandemic (Ollagnier et al., 2022). One explanation of this is that managers have/had less trust in the country's leaders finding a peaceful solution than in scientists developing treatments against the pandemic. Hence, the

Russo-Ukrainian war and wars in general could entail a higher capability of disruptions to SCs than the pandemic (Paché, 2022).

2.4 Supply chain disruptions

To better understand SC disruptions in ASCs, they should be defined and different types of disruptions should be explained. SC disruptions are "events that interrupt the regular flow of goods or services in a system" (Blackhurst et al., 2011). Various risks can cause unexpected deviations from planned SC performance and potentially lead to substantial SC disruptions (Carvalho et al., 2022). In case of the studied topic, a typical example is the disruption in sourcing from suppliers that are affected by the Russo-Ukrainian war. (Trade) war can be classified as a political disruption next to natural disasters (e.g., floods, earthquakes), biological disruptions (e.g., epidemics, pandemics), technological disruptions (e.g., cyber-attacks), and economical disruptions (e.g., inflation, recession) (Werner, 2022, p. 38).

A political disruption like the Russo-Ukrainian war is characterized by unpredictable demand, uncertain and unstable supply, instability of logistics channels, lack of labor, concerns about SC visibility and supply traceability, geopolitical instability, and the need for temporary, alternative SCs (Sodhi & Tang, 2021).

It shows that this type of disruption causes extraordinary impact on a company's SC and financial performance. Therefore, there is an incentive to reduce or prevent SC disruptions.

2.5 Supply chain resilience and viability

A promising approach to reduce risks and disruptions in SCs lies in the implementation of measures to make SCs more resilient or viable in the first place. Taking multiple **supply chain resilience** (SCRES) definitions into account, Tukamuhabwa et al. (2015) describe SCRES as "[t]he adaptive capability of a supply chain to prepare for and/or respond to disruptions, to make a timely and cost-effective recovery, and therefore progress to a post-disruption state of

operations – ideally, a better state than prior to the disruption." Adaptions made as a response to disruptions in the past years (COVID-19 pandemic, semiconductor shortage, Russo-Ukrainian war) resulted in various decision-making challenges (Ivanov & Dolgui, 2021). The pandemic particularly gave rise to a novel extension of the stability-based view of SCRES, namely **supply chain viability** (SCV) (Ruel et al., 2021; Ivanov et al., 2023). The models and associated frameworks of SC viability were proposed by Dmitry Ivanov who defines viability as "[…] the ability of a supply chain (SC) to maintain itself and survive in a changing environment through a redesign of structures and replanning of performance with long-term impacts" (Invanov, 2020). This extended viability-based approach to resilience is more complex and long-term-oriented covering SC adaptations and reconfigurations to disruptions with unknown scalability to ensure persisting performance of the SC, i.e., its survivability (Ivanov et al., 2023; Chervenkova & Ivanov, 2023; Ivanov & Dolgui, 2020). Alternatively, there is the differentiation between a closed-system view and an open system view. While SCRES focuses more on a "bounce-back" after a disruption impact in a closed system, SCV extends this with a viable, open system view including possibilities to "bounce-forward-and-adapt" (see Appendix) (Ruel et al., 2021). The new viability-based approach (respectively open system view) is less studied and should be analyzed more in the future (Wieland & Durach, 2021). This study pursues the analysis of SCV through the adaptation strategies of German car manufacturers in context of the Russo-Ukrainian war.

2.6 Supply chain resilience capabilities and viability framework

SCRES and SCV have been studied with practical examples like the COVID-19 pandemic. The Russo-Ukrainian war, however, gives reason and opportunity to continue the study of SCRES and SCV and potentially to add to or update finding from previous studies. As explained in the previous chapter, SCV is a relatively new extension to SCRES and demands more practical

analysis (Wieland & Durach, 2021). There are certain capabilities (i.e., main competencies) a SC ideally incorporates to be resilient (or viable). These are achieved through adequate practices (Han et al., 2020). In some of the reviewed literature, these capabilities are also presented as “elements”, “strategies” or “enablers” (Hohenstein et al., 2015; Tukamuhabwa et al., 2015; Křenková et al., 2023). For uniformity, they will be called “capabilities” which follows the recommendation of Jüttner & Maklan (2011). Hohenstein et al. (2015) discovered 36 capabilities and derived the following six as most important capabilities for SCRES: collaboration, human resource management, inventory management, predefined contingency plans and communication protocols, redundancy and visibility. Tukamuhabwa et al. (2015) present four capabilities (“strategies”): flexibility, redundancy, SC collaboration and agility. Křenková et. al (2023) builds on similar findings of Al Naimi et al. (2022) but focuses especially on agility. One of the most recent studies comes from Münch and Hartmann (2023) who came up with seven resilience capabilities as a combination of existing research and a cross-industry study that explored SCV in context of the COVID-19 pandemic. These capabilities are SC agility, SC collaboration, digital preparedness, flexible redundancy, contingency planning, human resource management and transparency and visibility.

Overall, capabilities of SCRES tend to be similar across research and summarized into four to seven capabilities. Besides Křenková et. al (2023) who puts an emphasis on agility, there appears to be no ranking in these capabilities.

With SCV building on SCRES and this study focusing on SCV in the German automotive industry, there is one study that should be highlighted particularly. Chervenkova and Ivanov (2023) studied adaptation strategies for SCV in the global automotive industry during the COVID-19 pandemic. It generalized the findings in a framework to build and maintain SCV called “Hybrid Adaptation Strategy”. The framework consists of three dimensions and five

viability capabilities (see Figure 1). The dimensions are “Adapting SCs and operations”, “Rethinking sourcing strategy” and “Building intertwined supply networks” (ISNs).

The five viability capabilities are adaptability, agility, collaboration, visibility and flexibility can be defined as follows:

Figure 1 “Hybrid Adaptation Strategy” based on Chervenkova & Ivanov (2023)

(1) **Adaptability** is the ability of a company to change their operations and processes to react to decisive challenges or to grasp opportunities (Pimenta et al., 2022).

(2) **Agility** is “[…] the ability to respond quickly to unpredictable changes in demand or supply […]” and is mainly influenced by visibility and velocity (Christopher & Peck, 2004). It is linked to responsiveness towards SC disruptions and emergencies to reduce their impact (Ponomarov & Holcomb, 2009).

(3) **Collaboration** in the context of SCs is the ability to work effectively with other entities/organizations for mutual benefit including subfactors like collaborative forecasting, communications, order postponement and risk sharing (Pettit et al. 2013).

(4) **Visibility** entails the use of information technology to enable transparency of information and awareness of the up-to-date supply chain landscape (Jüttner & Maklan, 2011). Companies are advised to establish holistic SC transparency about demand and material availability across multiple suppliers along the SC (Münch & Hartmann, 2023).

(5) **Flexibility** is the ability of a company or organization to adapt to changing requirements of its environment and stakeholders effectively and efficiently (Erol et al., 2010).

Although most of the viability capabilities have been found already in SCRES research, SC adaptability is a new addition introduced by the viability aspect that demands greater changes in SCs and processes due to profound environmental changes and disruptions.

The next part of this study will explore the SCV of German car manufacturers, partially guided by the framework of Chervenkova & Ivanov (2023). It appears to be a suitable foundation for a structured analysis of SCV of German car manufacturers in the context of the Russo-Ukrainian war due to the similarity of the research area and the focus of a certain industry, but in a different context.

3 Methodology

3.1 Research design

To answer the research questions of this study, qualitative and quantitative methods were chosen: (1) In-depth expert **interviews** were the primary method for data collection, since they offer the opportunity to discover underlying aspects and categories of the studied topic (Miles & Huberman, 1994). Qualitative interviews proof to be an adequate method in understanding the topic in the recent and still ongoing context which has not been studied in detail yet (Ellram, 1996). (2) Supplementary, **surveys** were used to quantify changes in SCV and as an attempt to rank SCV capabilities according to their importance which was seen as a research opportunity by Chervenkova & Ivanov (2023).

3.2 Data collection and analysis

To select experts for interviews and surveys, the following criteria were applied: (1) Experts had to be employed by German car manufacturers, (2) Experts had to work in a field related to the thesis topic to ensure qualified answers and (3) experts had to work in their job long enough to have information about the situation before the Russo-Ukrainian war to allow for "before and now" comparison of the situation. Examples of job fields are SCM, SCRES, logistics, procurement, risk management, capacity management or business continuity management. The objective was to find experts on similar job levels for better comparison. Anonymized information about the participants of the interviews and the survey can be found in the Appendix. Potential experts were searched on LinkedIn with key words relevant for the topic (see Appendix). Overall, 311 people were contacted for the interview and/or survey. Additionally, three personal contacts working in relevant positions were contacted.

Interviews: It was possible to interview 10 experts (7 resulting from LinkedIn requests and 3 personal contacts) from all major German car manufacturers, partially multiple employees per company. A semi-structured interview approach was applied to create comparability while offering flexibility to integrate important follow-up questions not part of the interview guide (see Appendix). The interview guide consisted of question about the war impact on SCs, adaptation measures/strategies for SCV and dimensions and SCV capabilities of the "hybrid adaptation strategy" framework. Interviews were conducted from October to December 2023 and lasted from 24 to 54 minutes (average duration: 37 min; total: 369 min).

Surveys: As with the interviews, it was possible to gather survey results from employees of all major German car manufacturers. The main objective of the survey was the quantification of the SCV capabilities of the "hybrid adaptation strategy" before the Russo-Ukrainian war and now. Additionally, a ranking of these capabilities according to their importance for SCV was asked. 36 anonymous surveys were answered via MS Forms from October to December 2023.

On average, participants took 3:17 min to answer the survey, were 39.2 years old, 11.1 years employed at the company and 4.4 years in the current position (see Appendix).

A mixed approach of deductive and inductive coding was used to analyze the acquired data. The deductive part is due to the defined research question. Most of the questions of the interview and the survey were designed in a way to answer these questions. That included questions regarding the framework of Chervenkova & Ivanov (2023) which was used to categorize certain data and to challenge its dimensions and capabilities for SCV in the new context of the war. To discover new dimensions or capabilities, findings from the collected data were used to inductively built new categories.

4 Results

4.1 Impacts and challenges for German car manufacturers

To answer the RQ1 *"What was/is the impact on supply chains?"* and to enrich and/or compare the impacts and challenges of the war that were described earlier, all experts were asked about the impacts the war had on their operations. The answers will be structured into overall, sourcing, social and financial impacts and challenges.

Overall: The Ukraine is an attractive sourcing country for German OEMs, because it offers high skilled low-cost labor. This makes sourcing of labor-intensive products, e.g., wiring harnesses, in Ukraine especially attractive (E4). One overall challenge was the viability of the SCs so that production at the final assembly line in Germany would not be disrupted. This was only partially achieved due to critical parts missing. Many OEM plants had to reschedule production, reduce it or shut it down temporarily.

Sourcing: When the war started, the assessment of the whole situation was a major challenge. There was great uncertainty regarding the development of the situation, what measures to take and when to take them and if the production of parts should be moved to other locations (E4; E10). All 10 experts mentioned that their employers' SC was affected in sourcing of parts

needed for final vehicle assembly in Germany. Besides wiring harnesses, parts like ball bearings, switches, buttons, wood panels, seat covers (e.g., leather) and glass were affected on supplier-level and saw temporary production downtimes or reductions. In some cases, plants in Ukraine were even destroyed. Effects in production were closely related to the availability of the workforce which was suddenly shaken – some people tried to leave the country and some went to war. On the other hand, in many cases, available labor wanted to continue working despite the war in order to secure their income and long-term, to not risk a sourcing relocation of OEM procurement to other countries. Transportation also saw a sudden loss of workforce. Some trucks were left behind or used to flee the country. Available trucks were sent on different routes due to uncertainty about possible transportation routes. Upstream supply was not only problematic in suppling German OEMs with finished goods from Ukraine, but also, upstream supply towards Ukrainian suppliers became a challenge (E5; E9). Border crossings to and from Ukraine were either not possible or delayed by traffic jams. A few OEMs sent additional trucks to the Ukrainian border to ease delays and prevent disruptions (E2; E5; E9). Another reason for additional trucks was that freight forwarders did not want to send their personnel into Ukraine. As a result, Ukrainian truck drivers continued to operate where possible within Ukraine and the trailers were handed over to foreign trucks at the border that then supplied the OEM (E9). Where supply was reduced or lost from Ukraine, the challenge of finding alternatives arose.

Social: A few experts mentioned challenges of social nature. Sourcing from a country that is in war brought up concerns of German OEMs. On the one hand, there is the safety of the suppliers' employees that should not be risked and on the other hand, cutting demand from these suppliers (e.g., by sourcing in other countries) would exacerbate the already adverse situation for the suppliers and their employees who, as mentioned wanted to keep working (E1; E5; E6).

Financial: The war caused/causes significant negative financial impact for OEMs (and suppliers). Reduced and halted production lines at OEM level have the largest negative

financial impact, because vehicles cannot be sold to the end customer. Production lines and tools on supplier level had to be transported to other plants outside of Ukraine. In some cases, the relocation was not possible (production lines destroyed or not accessible) and therefore, a second pair was created (mirrored) in a different country which required a substantial financial investment. Besides rising diesel prices caused by the war, OEMs supported with additional transports as mentioned above. (E1; E9; E10). E7 gave a further example for increased cost. Due to upstream delays, parts from Ukraine that usually would be sent to the Mexican plant of the German OEM via sea freight, required urgent air transport. Despite significant cost for air freight, management authorized the request in order to prevent disruption at the final vehicle assembly.

4.2 Adaptation strategies

To answer RQ2 "*What adaptation strategies were/are used for SC viability?*", experts described in interviews measures and strategies taken by their employer in the context of the Russo-Ukrainian war. Where applicable, the key adaptation strategies found in the answers will be presented guided by the dimensions of the "hybrid adaptation strategy" framework of Chervenkova & Ivanov (2023).

Adapting SCs and operations: The overarching adaptation found in SCs and operations is diversification. First, all 10 experts said their employer relocated parts of the supply chain, i.e. production lines and tools were relocated to different locations, often with the support of OEMs. Part of the relocation happened within Ukraine, but the most was sent to other countries like Romania, Bulgaria or Morocco (E1). In some cases, employees required for the labor-intensive tasks were also relocated to the new production line (E4). E5 explained that there currently is a second wave of relocations, because the first one had to be ad-hoc without optimal location planning. Second, critical production lines and tools were proactively duplicated to other countries in case the original production line could not be operated any more. Two experts

mentioned that redundant production lines are ready in other countries, but currently not needed (E1; E5). Third, if the OEM had alternative suppliers in other countries, capacity was increased there. For example, one OEM had a supplier in Thailand that was able to increase its seat cover production and partially substitute the Ukrainian supplier (E8). Fourth, where possible, production on supplier level was kept unchanged in Ukraine and risks were closely monitored. In general, risk monitoring is a strategy referred by multiple experts. This includes a range from capacity and demand monitoring across all OEM entities up to tools using artificial intelligence to warn of acute risks (attacks, traffic problems, natural disasters etc.) in certain areas. (E2; E7; E9; E10). Additionally, tracking and tracing of transports was increased (E9). As already mentioned, measures were taken to ensure the transportation of goods to the OEM. In Ukraine, trucks were sent on different routes because of many unknowns (e.g., infrastructure, traffic jams, …). After the Ukrainian border, additional transports organized by OEMs reduced the supply delays. At final assembly level, some orders had to be rescheduled e.g., if certain ordered features were not available, production had to be paused or the finish of production was postponed. Many German OEMs left out missing parts in production, parked the cars and only finished the production when parts became available again (E9). Alternatively, a strategy of "upgrading" was applied, i.e., parts meant for more expensive product lines were installed if their availability was higher. This strategy significantly saved time because no timely certification procedures for alternative parts had to be made (E2). Lastly, speed was also increased in strategic procurement through higher tender award value limits, meaning less approvals were needed in sourcing committees (E9).

Rethinking the sourcing strategy: As mentioned for SC adaptations, all 10 experts mentioned the relocation of parts of the SC. This, besides being an ad-hoc adaptation also reflects a rethinking of the sourcing strategy to countries or regions with less to no conflict. Not only production location of suppliers, but also the sourcing of raw materials was reconsidered. E7

gave the example of wood panels that their Tier-1 supplier sourced only from Russia and Ukraine. As an alternative, they found a supplier in southern Europe that could produce the same part from different looking and more expensive wood. Interestingly, customers prefer the new look, hence the OEM continues to source the once thought alternative. Many OEMs tried to increase their stock of critical parts ("banking") and even recommended Tier-1 supplier to "bank" critical parts from their upstream suppliers to reduce disruption risks (E1; E5; E10). The challenge there is to find the balance between safety stocks and employed capital (E4; E5). Another way to reduce the risk of SC disruptions is the application of dual or multi sourcing (not just one supplier is contracted if possible) which gained importance through the war (E2; E5; E6; E7; E10). In case of a supplier being in a riskier region, potential back-up suppliers are already defined (E7). As a last direct example, the reduction of variance was applied (e.g., fully equipped wiring harnesses where often not all connectors where needed per car) (E1).

Building intertwined supply networks: "An intertwined supply network (ISN) is an entirety of interconnected supply chains (SC) which, in their integrity secure the provision of society and markets with goods and services" (Ivanov & Dolgui, 2020). An illustration for this is the cooperation of OEMs and companies from the healthcare sector when both shared knowledge and capacities to scale-up the production of ventilators during the pandemic (Chervenkova & Ivanov, 2023). Being asked if similar cooperation happened/happens in the context of the Russo-Ukrainian war, none of the experts found suitable examples. This might show the dimension of "building intertwined supply networks" is not applicable in this new context. Nevertheless, some experts gave valuable examples that do not directly fit to ISNs. One of the tier-1 suppliers in Ukraine was in contact with authorities to find women who could spontaneously replace men in production who were drafted by the military (E7). Another example came from E3 and E10: During peaks of semiconductor shortages (more related to the pandemic), some OEMs considered buying products like headphones to take out the required

chips they needed for their cars and E10 said they know of one case where washing machines were bought just for that reason and it was still cheaper than not being able to finish the production of the car.

Using taskforces: As a new dimension to the viability framework, "using taskforces" should be proposed. Eight out of the ten interviewed experts specifically addressed the use of "taskforces" as a strategy for SCV in the context of the war. The described taskforces consist of employees from different departments (e.g., procurement, quality, engineering, research and development, SCM or capacity management) of an OEM and sometimes also other companies (e.g., consultancies) that solely work on a given problem. They closely cooperate to solve problems with high velocity. In the analyzed context, their tasks range from risk assessment and tracking to contingency planning, alignment with suppliers and management all the way to working "on the ground" in upstream supply chains. In particular, E1 & E5 talked about how their companies put lots of effort in these taskforces by renting additional space where about 300 people from the above-mentioned departments, important suppliers, consultancies and management worked together in an agile "war room setting". Suppliers had their own rooms and OEM departments had their own areas where suppliers and the OEM could quickly meetup to discuss ad-hoc measures. Twice a day, there were committees with the board to take decisions (and approve transactions) (E5). The consultancies supported by structuring projects, reporting measures and tracking risks and capacities (E1; E5). Overall, taskforces played a significant role in ensuring agility and viability of the SC.

4.3 Supply chain viability capabilities

After analyzing the impacts of the war on German ASCs and the different dimensions of how German OEMs reacted, this part of the research will focus on the SCV capabilities to answer RQ3 and RQ4. To answer RQ3 "*Which SC viability capabilities are best/least developed, and*

which are considered most important for SCV?", experts were asked in the interviews to give an estimate and reasoning for best and worst developed capabilities (some gave multiple capabilities). The ranking of the perceived most important capability for SCV was asked in the survey.

Best developed: Five out of ten experts said **agility** is the best developed SCV capability of their OEM because of quick changes in the SC (e.g., quick communication and support of supplier, exchange of supplier, relocation of production lines) (E3; E4; E7; E9; E10). **Flexibility** was also chosen by five out of the ten experts for similar reasons as agility plus flexible capacity management with suppliers and flexible collaboration in the OEM group (E1; E3; E4; E5; E6). **Collaboration** was mentioned by three experts as the best developed SCV capability due to positive feedback received from suppliers, trust and support given in emergencies instead of insisting on contracts and close collaboration in the OEM group (E2; E6; E8). **Adaptability** was chosen once for the ability to adapt processes and incorporate learning effects from previous cases (E9). **Transparency** proved to be the least best developed capability. It was mentioned once, but with a limitation. E4 stated that their OEM could quickly get transparency with software tools, but only to Tier-1 supplier level.

Taskforces must be highlighted in the part of best developed SCV capabilities, because they are considered a major factor for increased agility, flexibility, collaboration (E1; E4; E5; E6; E7). E6 even stated that taskforces help their OEM to improve all SCV capabilities.

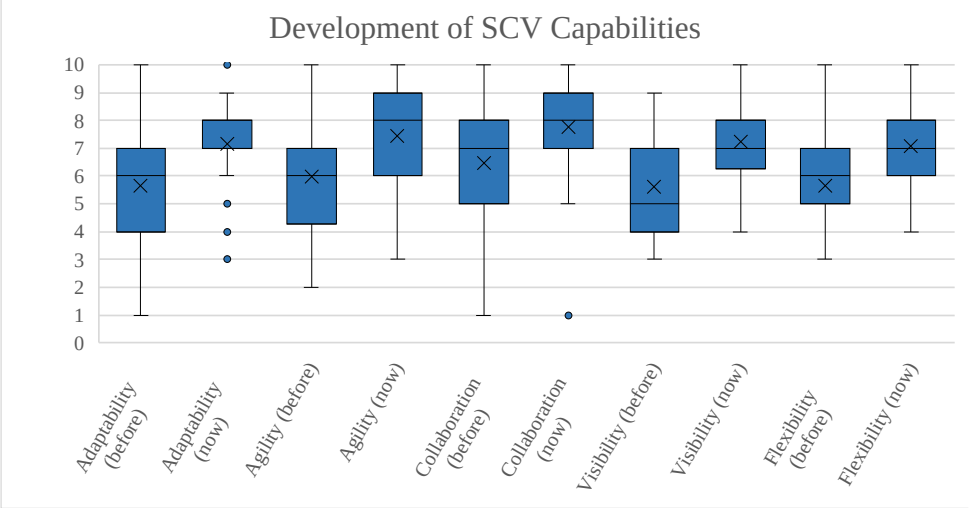
Least developed: Five out of ten experts thought, **visibility** was least developed at their OEM. Not only was it chosen least for best developed, but also most often chosen for least developed. The choices were made for the same reasons. Visibility is considered developable mostly driven by lack of it beyond Tier-1 suppliers (suppliers, materials, cost etc.) which is consistent with the literature part of ASCs. (E1; E4; E5; E7; 10). Regarding the visibility, E4 and E8 highlighted the "CATENA X" association as one solution for more visibility in the SC (in the future). It is

an open-source automotive network that aims to achieve transparency across the whole SC (Catena-X, n.d.). German and European OEMs have been joining the network. Together, they try to map all suppliers from Tier-1 to Tier-n and build a consistent database. European suppliers are already mapped in the database and now, the association is looking at the US, Asia, and Africa (E8). Additionally, E7 mentioned that their OEM nowadays carefully considers the visibility through the supplier tiers in new supplier tenders. Two experts selected **adaptability** as least developed. E8 said that processes are rigid and complicate adaptions. E2 mentioned it for a general reason because there would always be unpredictable situations that require adaptations and therefore adaptability always needs more development. **Collaboration** was also selected by two experts. One, because there is a lack of information which could be improved by further collaboration (E9). Two, the OEM could be more accommodating in the payment terms, i.e., pay suppliers who often operate with minimal financial buffer quicker (E6). Lastly, **flexibility** was chosen once due to strict laws and requirements that hinder quick adaptations (E4). For both, best and least developed SCV capabilities, it is important to notice that few experts thought agility, flexibility and adaptability are intertwined which made it difficult to differentiate them (E2; E3; E6; E9).

SCV capability ranking: To answer the last part of RQ3, survey participants were asked to rank the five SCV capabilities of Chervenkova and Ivanov (2023) by the perceived importance for SCV. As a result of 36 conducted surveys, the following ranking was retrieved: (1) Visibility, (2) Adaptability, (3) Collaboration, (4) Flexibility and (5) Agility (see Appendix).
Visibility received 16 first ranks, followed by adaptability, collaboration and flexibility with 6 first ranks and agility which received 3 first ranks.

SCV capability development: To answer the RQ4 *"How have capabilities developed?"*, survey participants were asked to compare the five proposed SCV capabilities before the Russo-Ukrainian war to now on a scale of one to ten. Overall, all five capabilities improved from the experts' point of view (see Figure 4). On average, capabilities improved by 25% (1.5 points on the scale of one to ten). Visibility improved the most by 29%, followed by adaptability (27%), agility (25%), flexibility (25%) and collaboration (20%). Although collaboration improved the least in percent, it showed the highest average starting number of 6.5 and continued to show the highest current number of 7.8. Visibility growing the most in percent, still only reaches a current result of 7.3 in comparison.

Figure 2 Development of SCV capabilities



5 Discussion

All interviewed experts were able to give valuable insights on the dimensions "adapting SCs and operations" and "rethinking the sourcing strategy" from the "hybrid adaptation strategy" framework. However, the dimension "building ISNs" was not applicable to the studied context. Instead, the new dimension "using taskforces" was derived from the answers. In the capability ranking of the survey, experts ranked "visibility" and "adaptability" as most important for SCV. This is particularly interesting because the estimation of the best/least developed capabilities from the interviews shows that "visibility" and "adaptability" are the least developed. Hence,

there seems to be a discrepancy between “what is required” and “what there actually is” and these should be developed further in the future. The evaluation of the five capabilities shows overall improvement of all. Even though “visibility” achieved the best improvement comparing the classification of before the war and now there still seems to be the most room for improvement. This goes in hand with the results of the perceived best/least developed capabilities.

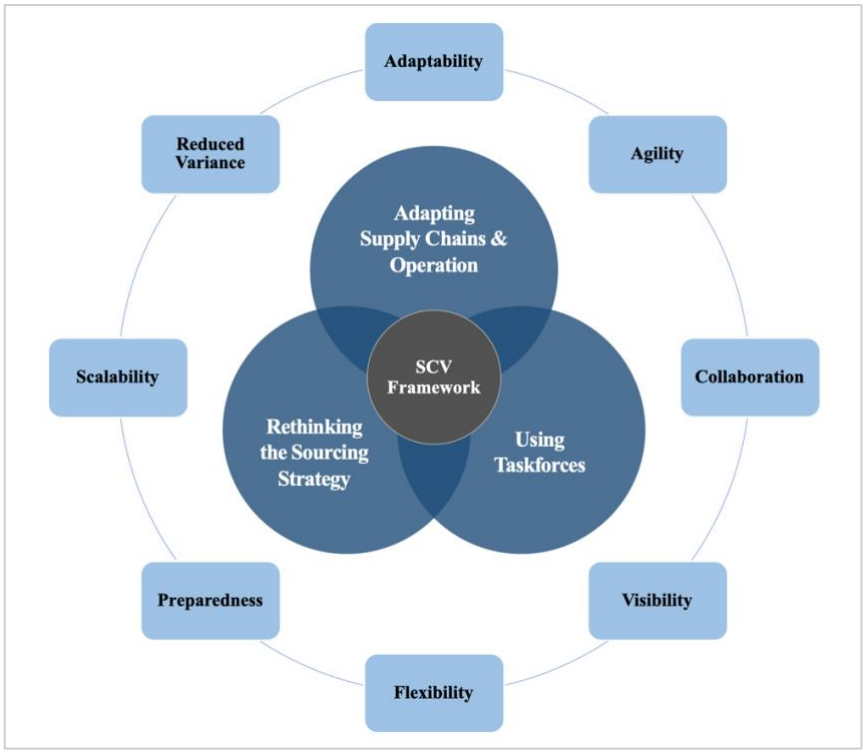
In the context of this research and through the findings of interviews and surveys, several potential **new SCV capabilities** were derived.

1. **Preparedness**: This capability consists of a modular “toolbox”, taskforces and learning effects. E1 and E9 described a prepared “toolbox” that allows for more effective and efficient measures. They had blank processes and projects (e.g., project structure, taskforce structure, schedules, list of open points, …) prepared that could be applied to a certain situation (E1). Taskforces were still existent from previous crises (pandemic, semiconductor shortage, Suez Canal) and ready to be “deployed on a new problem” (E1; E9). With the previous crises also came learning effects that could be applied to the new context and played an important role in general preparedness (E9).
2. **Scalability**: When the war started, being able to scale-up alternative production and transportation was crucial to prevent SC disruptions. E1 mentioned the scalability of capacity. Suppliers wouldn’t have employees focusing on this. So it is of great importance that the OEM brings knowledge and skills to relocate production and connections to agencies that can support in recruiting of skilled new labor which was a bottleneck.
3. **Reduced variance**: Cars are usually offered with thousands of configuration possibilities. In extreme situations when the supply is affected, singe missing parts caused delays and disruptions. Reduced variance helped OEMs to speed up sourcing and prevent further production problems. In practice, E1 gave the already mentioned example of wiring

harnesses with more connectors to fit to more configuration options. E2 gave the example of more premium parts being handed down in the product range to save time. However, this capability needs to be considered carefully because it can imply higher cost.

The analyzed dimensions and capabilities should be used to create a **new SCV framework** in the studied context of German car manufacturers and the Russo-Ukrainian war (see Figure 5). It builds on three dimensions, namely "adapting supply chains and operations", "rethinking the sourcing strategy", and "using taskforces". "Building ISNs" from the original framework by Chervenkova & Ivanov (2023) does not apply in the studied context and therefore should be replaced. Additionally, 8 interconnected capabilities are important for SCV: "adaptability", "agility", "collaboration", "visibility", "flexibility", "preparedness", "scalability" and "reduced variance".

Figure 3 Adjusted SCV framework in the context of the Russo-Ukrainian war



6 Conclusion

The objective of this study was to find answers to the four research questions presented in the introduction. Most novel finding could be found in the answers of RQ2-RQ4.

The interviews showed there was substantial impact from the war on the SCs, similar to the presented impacts and challenges in the literature review. Impact happened on overall, sourcing (and therefore production), social and financial level. Despite the severity – or maybe because of it – German OEMs acted quick end effective and were able to keep disruptions at a minimum and (re)built viable SCs. Taskforces played a major role in achieving the results.

Regarding adaptation strategies of the SCV framework, it was found that ISNs were not part of the current context and were replaced by the new dimension of taskforces. The best developed SCV capabilities are "agility" and "flexibility". The least developed are "visibility" (=transparency) and "adaptability" while they are also considered most important for SCV. These two need specific attention from OEMs and researchers.

The study presents major novelties in the SCV research. While existing SCV research focuses on the pandemic, this study analyzed a more recent context. Existing dimensions and capabilities of SCV were challenged and new ones added. Taskforces were identified as an important measure to overall improve SCV. Newly found SCV capabilities that help/helped OEMs during the war are "preparedness", "scalability" and "reduced variance". Beside the new capabilities, OEMs should focus on "visibility" and "adaptability" and develop specific actions to improve them. Finally, a new framework to achieve SCV in the current context was developed, consisting of three dimensions and eight capabilities.

7 Limitations

This thesis studied the SCV of German car manufacturers from sourcing to production in the context of the Russo-Ukrainian war. The topic could imply the limitation of generalization and

external validity since it considers only a restricted part of the SC, a restricted geographical area (Germany and supplier mostly from Ukraine and Russia) and all is analyzed in a specific context. Therefore, the findings might not be applicable to other parts of the supply chain, other regions or contexts. However, one of the experts stated that implications are highly similar to other crises (E8). Furthermore, learning effects from the pandemic and semiconductor shortage are currently applied (e.g., through taskforces) which could be a sign that the learnings from the current context can be used for future crises. 10 experts participated in interviews and 36 in the survey. This sample size therefore is limited and conclusions derived from it should be treated carefully. To reduce bias, experts of all German car manufacturers and different departments related to SCV took part in the research. Another limitation could come from information bias because experts might have an overly positive image of their company or want to protect their own or their companies' image. Also, deriving joint conclusions from two separate data collection methods might be limited. Lastly, the empirical data was only collected between October and November 2023. Since the war is still ongoing, further implication could appear in the future.

8 Future research

Future research could study the topic of SCV in the same context and with a different industry or stay in the same industry and "update" the research by studying a different context (e.g., Arab–Israeli conflict, with semiconductors coming from Israel).

Regarding SCV dimensions, research could focus on the optimal composition and working modes of taskforces. Additionally, research could focus on effective and specific measures to improve important SCV capabilities (e.g., what to include in the "tool box" of "preparedness" or an optimal "reduced variance" of parts optimized for risk and cost).

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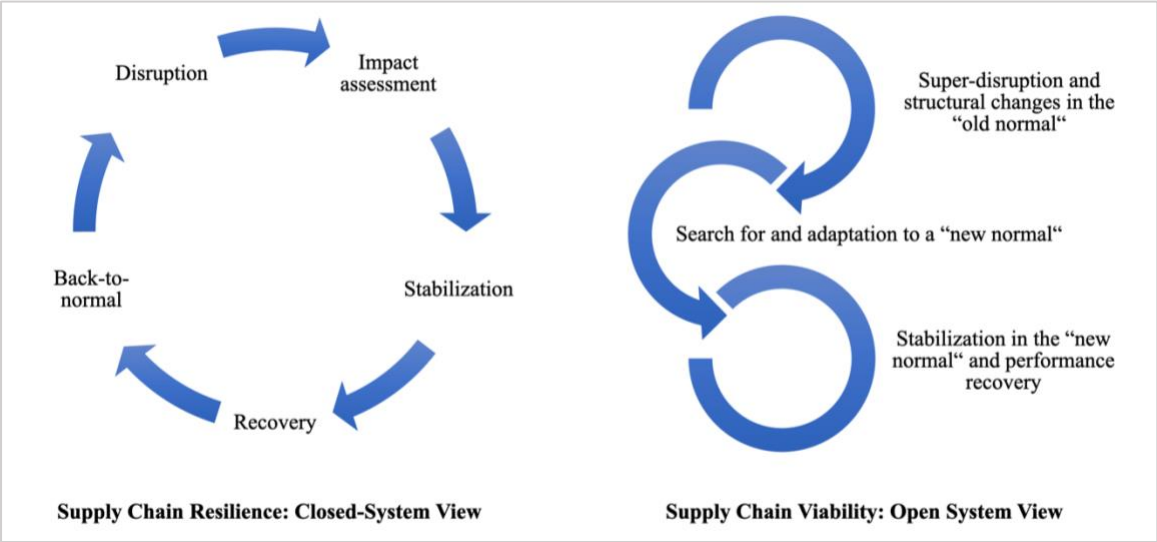
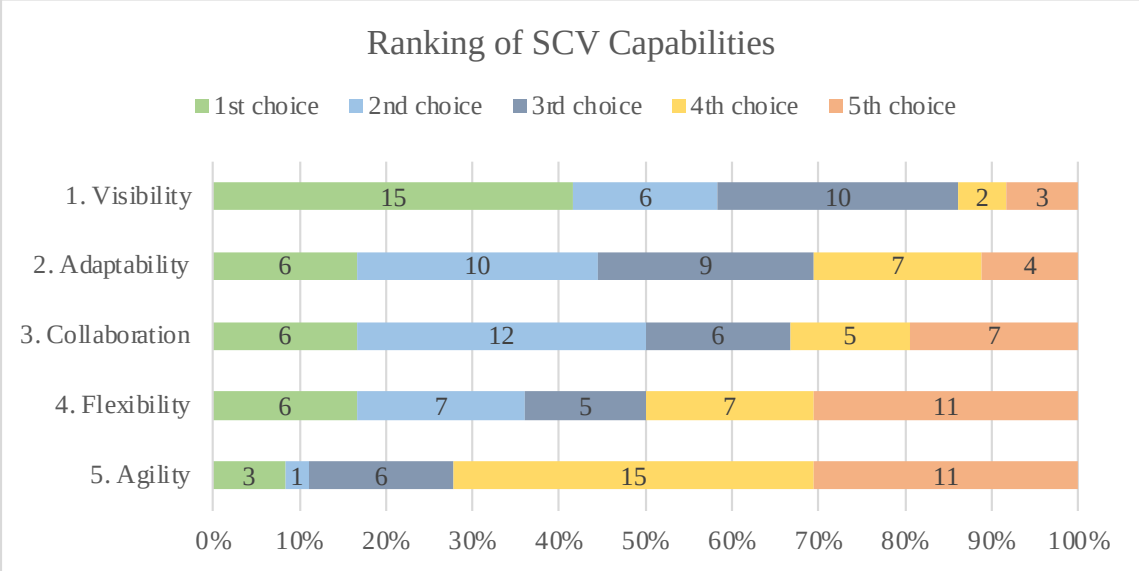
10 Appendices

SCV as an extended resilience perspective based on Ruel et al. (2021):



Ranking of SCV Capabilities:

Figure 4 Ranking of SCV capabilities



Overview of interview participants:

No.	Job position at German OEM	Experience (years)		Age	Interview Length (min)
		In company	Current position		
E1	Head of Supplier Process Optimization	18	7	38	37
E2	Manager Procurement Resilient Supply Chains	22	6	47	24
E3	Head of Supply Chain Management	22	3	46	31
E4	Senior Manager Capacity Management	17	5	35	30
E5	Team Lead Procurement	7	2	31	46
E6	Business Continuity Manager	26	6	50	32
E7	Supplier Capacity Manager	7	5	34	54
E8	Supplier Capacity Manager	2	2	52	26
E9	Procurement Manager - Logistics	4	4	27	52
E10	Procurement Manager	2	2	27	37
		∅ 13	∅ 4	∅ 39	∅ 37

Overview of survey participants:

No.	Job position at German OEM	Experience (years)		Age range
		In company	Current position	
1	Project Lead Procurement	5	2	25-34
2	Procurement Manager	6	4	25-34
3	Procurement Manager	5	4	25-34
4	Director Supplier Process Optimization	18	7	35-44
5	Procurement Manager	5	2	25-34
6	Supplier Manager	2	2	25-34
7	Project Lead Resilient Supply Chain	22	2	45-54
8	Procurement Manager	4	4	25-34
9	Capacity Manager	2	2	35-44
10	Procurement Manager	2	4	25-34
11	Supplier Capacity Manager	3	4	25-34
12	Head of Supplier Risk Management	20	1	35-44
13	Head of Supply Chain	22	3	45-54
14	Manager Supply Chain Management	22	4	35-44
15	Manager SC & Supplier Management	19	13	45-54
16	Procurement Manager	12	12	35-44
17	Director Supplier Capacity Management	15	2	35-44
18	Supplier Capacity Manager	2	2	45-54
19	Business Continuity Manager	25	12	45-54
20	Supply Chain Manager	11	4	35-44
21	Head of Purchasing	10	2	35-44
22	Risk Manager Supply Chain	9	4	45-54
23	Director Strategic Procurement	16	3	45-54
24	Supplier Capacity Manager	7	4	35-44
25	Plant Manager	4	24	45-54

26	Supplier Manager	15	7	45-54
27	Manager Supply Chain Sustainability	9	3	35-44
28	Director Supplier Network	18	3	35-44
29	Supplier Capacity Manager	7	1	25-34
30	Procurement Manager Wiring Systems	22	5	35-44
31	Inbound Logistics Manager	7	2	35-44
32	Lead Bottleneck Management	11	2	35-44
33	Director Raw Material Procurement	5	1	35-44
34	Risk Manager Procurement	9	4	25-34
35	Director Logistics Planning	15	3	45-54
36	Procurement Manager	5	2	25-34
		∅ 11	∅ 4	∅ 39

Key words for expert search on Linkedin:

- supply chain management
- procurement management
- sourcing
- lead
- manager
- team lead
- production
- operations management
- wiring
- resilience
- capacity
- supplier management
- supplier
- network
- taskforce
- plant

- continuity
- crisis

Interview Guide:

1. What do supply chain resilience and supply chain viability mean to you? Do you have any examples?

- *Definition: Supply Chain Resilience*
- *Definition: Supply Chain Viability*
- *Information: The following questions all relate to supply chains (from procurement to production) in the context of the war in Ukraine and the resulting impact on SCs.*

2. On the subject of supply chain resilience/viability, can you please give examples of strategies or measures that your company has used or is using to make the supply chain more resilient or viable in the first place?
3. In your opinion, what are the decisive factors for a supply chain to remain resilient/viable in times of geopolitical instability and conflict?

- *Hybrid adaptation strategy framework by Chervenkova & Ivanov (2023) shown*

4. In relation to the three internal dimensions of the Hybrid Adaptation Strategy framework, please provide examples from your organization's supply chain (from sourcing to production) related to the war in Ukraine, if applicable.
5. Which of the five supply chain viability capabilities do you think is the most developed in your organization's supply chain (from sourcing to production) and which is the most challenging, and why do you think this is?
6. Can you think of another dimension or capability that is not listed in the framework?
7. Do you have any other information you would like to share? In your opinion, was something important not asked?

- *Personal information asked*

Survey Guide:

- *Definition: Supply Chain Resilience*
- *Definition: Supply Chain Viability*
- *Information: The following questions all relate to supply chains (from procurement to production) in the context of the war in Ukraine and the resulting impact on SCs.*
- *Following questions answered on a scale of 1-10 (1=very low, 10=very high)*

1. How would you rate your company's supply chain adaptability before the start of the war in Ukraine?
2. How would you rate your company's current supply chain adaptability?
3. How would you rate your company's supply chain agility before the start of the war in Ukraine?
4. How would you rate your company's current supply chain agility?
5. How would you rate your company's supply chain collaboration before the start of the war in Ukraine?
6. How would you rate your company's current supply chain collaboration?
7. How would you rate your company's supply chain visibility before the start of the war in Ukraine?
8. How would you rate the current supply chain visibility of your company?
9. How would you rate your company's supply chain flexibility before the start of the war in Ukraine?
10. How would you rate your company's current supply chain flexibility?
11. Please rank the 5 capabilities according to your perceived importance for supply chain viability

a. Adaptability

b. Agility

c. Collaboration

d. Visibility

e. Flexibility

12. Can you think of any other capabilities for SC Viability that are not mentioned in the framework?

- *Personal information asked*