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Exploring the role of Manufacturing-as-a-Service for improving Supply Chain Resilience

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Abstract: Supply chain resilience (SCR) has been a key focus for researchers and businesses over the past decade. The Covid-19 intensified this attention, highlighting critical issues such as raw material shortages, unpredictable demand shifts, and logistics and supply chain challenges. These disruptions have significantly impacted global supply chains in the last two years. Manufacturing-as-a-Service (MaaS) has emerged as a new service-oriented manufacturing paradigm inspired by cloud manufacturing. MaaS has the potential to support companies in increasing their SCR, e.g., by providing access to a wide pool of suppliers. However, literature is scarce in investigating this relationship. This paper aims to fill this gap through 15 expert interviews exploring the link between SCR capabilities and MaaS. Results suggest that MaaS supports supply chain flexibility, velocity, redundancy and visibility. For the experts, MaaS has a detrimental effect on supply chain collaboration, which is considered an antecedent of SCR for literature. Finally, the functionalities needed in a MaaS system to support SCR are discussed.

Keywords: Supply chains and networks; Supply Chain Management; Risk Management; Industry 4.0; Manufacturing-as-a-service; Resilience; Supply chain capabilities.

1. INTRODUCTION

In today's highly interconnected world, supply chains (SC) have become increasingly global, and value networks are more interlinked than ever before. Businesses are nowadays exposed to a range of risks and disruptions that threaten their operations, productivity, and profitability (Montoya-Torres, 2021). In this context, supply chain resilience (SCR) has gained significant attention in both academic literature and industry practices as a vital capability. Indeed, resilience as a concept has applications across multidimensional and multidisciplinary fields such as engineering, psychology and ecology (Castillo, 2023).

Resilience focuses on proactively mitigating disruptions and unexpected risks and adapting to them to maintain service levels (Gruchmann et al., 2024). Additionally, it involves a reactive dimension, emphasizing learning from disruptions and risks in the firm's external environment and capitalising on emerging challenges to enhance the firm's stability. The concept of SCR has thus shifted from merely responding and recovering from disruption to encompassing – in addition to responding and recovering – capabilities to prepare and anticipate, as well as adjusting and learning from disruptive events (Sawyerr & Harrison, 2019). Ivanov (2023) has described resilience as the SC's immune system that helps living creatures prepare, fight and recover from stressors.

Meanwhile, digital technologies emerged to support SCR (Ivanov, 2024; Xue et al., 2025). Advancements in technology over the past decade, particularly in cloud computing, have been innovatively applied in industrial contexts through concepts such as cloud manufacturing and cloud supply chain (Ivanov et al., 2022). This has facilitated the emergence of Manufacturing-as-a-Service (MaaS), a concept that has recently gained significant momentum, remarkably during the last 15 years (Tedaldi & Miragliotta, 2023). MaaS provides companies access to a broader pool of servitised manufacturing capabilities and suppliers, offering service consumers alternative options that enhance order fulfilment rates (Tedaldi & Miragliotta, 2023). This is particularly relevant in the context of unplanned risks and disruptions, where companies can swiftly capitalise on available capacities and alternative solutions. However, literature investigating the implications for resilience of the adoption of MaaS is limited. Therefore, we pose the following research question:

RQ: How can MaaS improve supply chain resilience?

Expert interviews are used to explore how MaaS can contribute to SCR by enhancing SCR capabilities.

2. BACKGROUND

2.1 Manufacturing as a Service (MaaS)

Over the past few years, with the evolution of cloud computing services, crowdsourcing, and "everything as a service", MaaS has emerged as an extension of these concepts. MaaS was conceptualized as early as the 1990s and has been described as a new model that provides customers with flexible contracts, rapid responses, and efficient customer-supplier transactions, characterised by information-dense content (Goldhar and Jelinek, 1990). Moreover, rapid technological upgrades, particularly in cloud computing, have directly led to the development of cloud manufacturing, which, in turn, has

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enabled MaaS as we know it today (Tedaldi and Miragliotta, 2023).

MaaS can be defined as the offering of manufacturing resources and capabilities that can be shared and utilised by customers according to their specific manufacturing needs. Broadly speaking, there are two main categories of drivers for MaaS. On one hand, there are market drivers, such as the interconnectedness of resources and economics, customer requirements and expectations, and the demand for shorter product life cycles. On the other hand, technological drivers include advancements such as cloud technologies, cyber-physical manufacturing systems, innovative manufacturing technologies like additive manufacturing, and big data analytics. (Bulut et al., 2021).

Bettoni et al. (2018) explore the development of a multi-sided digital manufacturing platform designed to utilise firms' unutilised capacities. Their paper describes the underlying principles of the MANU-SQUARE platform, which has three primary aims: to integrate value chain actors in providing product-service solutions, to utilise redundant capacities, and to support SMEs and startups by connecting them with the required service suppliers. Such initiatives are gaining momentum within European industries and internationally. For example, Protolabs is based on the MaaS concept, enabling manufacturing customers to prototype and produce low-volume parts up to scaling manufacturing projects.

2.2 Supply chain resilience capabilities

SCR is defined as "the adaptive capability of a supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function." (Ponomarov and Holcomb, 2009, p. 8). Therefore, SCs can be considered resilient if they possess the "adaptive capability […] to make a timely and cost-effective recovery, and therefore progress to a post-disruption state of operations" (Tukamuhabwa et al., 2015, p. 8). To make the SC resilient, it is first crucial to focus on single organisations. As for SCs, the resilience of organisations depends on their capabilities, which represent the "ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments" (Statsenko et al., 2024). In line with Statsenko et al. (2024), SCR capabilities are:

- Flexibility: "The ability of a firm to adapt to unexpected or novel circumstances while changing for alternative supply chain options" (Statsenko et al. 2024, p. 5)
- Velocity: "The ability of a firm to be able to quickly react to market changes/ events." (Statsenko et al., 2024, p. 5)
- Visibility: "The ability of a firm to see the SC though an end-to-end perspective, preventing interventions and overreactions" (Statsenko et al., 2024, p. 5)
- Redundancy: "Having supply chain excess capacity in terms of production, resources, transportation, multiple suppliers, safety stock, strategic inventory, emergency backup/ storage facilities" (Statsenko et al., 2024, p. 5)
- Collaboration: "The ability of two or more firms to plan and execute SC operations to achieve common goals through shared vision and commitment" (Statsenko et al., 2024 p. 5)
- Awareness & Alertness: The awareness of SC risk management importance, the ability to collect data, make sense of them and interpret them for being prepared.

For each capability, a catalogue of enablers is established, grounded in the existing literature, which can pertain to organizational practices, human factors, or technological tools. Enablers are practices and tools that enable companies to explore alternative SC options when a disruption occurs. **Flexibility** is enabled by organisational practices in purchasing, product design and outbound logistics processes (Ali et al., 2017), which allow companies to know possible suppliers to use, or to have various alternatives for product design or distribution channels (Braunscheidel and Suresh, 2009). Moreover, flexibility is enabled by asset servitisation, that might belong to the same company, e.g. other companies plants within a group, or to other companies. Human factors are also relevant in providing flexibility through multi-skilled employees (Kamalahmadi and Parast, 2016). **Redundancy** can be attained through the following enablers: companies can keep redundant resources in the form of stocks of raw materials, components, finished products, machinery, people or suppliers (Chouwdhury and Quaddus, 2015; Kamalahmadi and Parast, 2016). **Awareness and alertness** organizations can be prepared to face risks by defining recovery plans (Ali et al., 2017) and organizational roles (Kamalahmadi and Parast, 2016; Sáenz and Revilla, 2014) to manage them. Moreover, advanced systems for disruption prediction can support early detection (Kamalahmadi and Parast, 2016). **Visibility** is obtained by leveraging digital solutions for information sharing (Ivanov, 2024; Brandon-Jones et al., 2014; Ali et al., 2017). Anyway, these should be strongly supported by organizational actions when the information is shared outside the organization. **Velocity** is supported by organizational and human-related practices, such as organizational design (Christopher and Peck, 2004) and Human Resource Management (Kamalahmadi and Parast, 2016), while it is favoured by technological solutions supporting decision-making (Scholten and Schilder, 2015). **Collaboration** requires information sharing on risk sources detection and implications, while it is enabled by agreements among the parties (Ali et al., 2017; Christopher and Peck, 2004; Scholten and Schilder, 2015).

2.3 MaaS and supply chain resilience

There is limited research on the relationship between MaaS and SCR. However, literature suggests that MaaS contributes to some resilience capabilities, namely flexibility, velocity, redundancy and collaboration. MaaS improves flexibility by gathering and offering a wider set of providers, making the search for alternative providers faster (Fisher et al., 2018; Kedzia 2024). The platform allows more flexible contractual relationships (Tedaldi and Miragliotta, 2023) with variable time horizons (small or long run) depending on the user's needs (Fisher et al., 2018). MaaS has a positive impact on velocity, it makes the search for alternative providers, the negotiation and the order placement faster than traditional approaches (Fisher et al., 2018; Kedzia 2024). MaaS supports redundancy, when companies can leverage the ability of the platform to support the search for alternatives as providers (Tedaldi and Miragliotta, 2023) before the disruption. Finally, it supports the development

of buyer-supplier collaboration, enabling customer participation in product design and high-information-content transaction (Tedaldi and Miragliotta, 2023; Kedzia 2024).

3. METHODOLOGY

To answer the RQ, this study exploited expert interviews. Data was collected through semi-structured interviews. Selected participants have expertise in SC management and SC management-related risks. **Errore. L'origine riferimento non è stata trovata.** reports for each expert (E) the job position and the reference industry. Participants belong to 6 companies (C), except for E11, who is an academic.

Table 1. Experts' sample

	Role	**Industry**
E1 (C1)	Production Manager	Home appliances
E2 (C2)	Head of Import and Logistics	Home appliances
E3 (C2)	Purchasing Manager	
E4 (C3)	Head of supply chain logistics management	Smart Metering and Energy Management
E5 (C3)	Senior Vice President Supply Chain	
E6 (C3)	Sourcing Vice President	
E7 (C3)	Heading up Product Management	
E8 (C4)	Purchasing & Cost Specialist	Home appliances
E9 (C4)	Head of Supply Chain Management	
E10 (C5)	Supply chain manager	Automotive
E11	Supply chain management	Academics
E12 (C6)	Former-Supply Chain Director Consumer Product Division	Cosmetics
E13 (C4)	Head of inbound supply chain	Home appliances
E14 (C6)	Purchasing director	Cosmetics
E15 (C4)	Logistic region manager	Home appliances

Interviews were conducted in two waves. The first set, seven in total, was conducted with company managers participating in the project funding this study. They are manufacturing firms operating in the white goods sector (C1 and C2) and the energy and water sectors (C3). Contrary, for the second set, we resorted to the AIDA portal to spot other companies operating in the manufacturing industry, among which white goods, automotive, and cosmetics sectors. To cover a wide range of industries, companies in the cosmetics and automotive sectors were selected. This choice was driven by the need to explore different sectors compared to the white goods one. The remaining participants were selected through purposive sampling, focusing on SC management experts with significant experience in identifying risks and developing resilience capabilities. Once identified, companies and SC-related representatives were contacted via LinkedIn. Finally, a professor specializing in MaaS was also interviewed to provide theoretical insights, corroborating the practical perspectives of the industry experts. All interviews were conducted through Microsoft Teams and lasted approximately one hour. Questions covered two key themes: SC risks and SCR capabilities and the potential impact of MaaS on SCR.

All interviews were recorded and transcribed upon permission request, except for E8 and E12. For these two interviews, we did our best to take reliable and truthful notes. To enhance the quality and clarity, transcripts were reviewed and edited before data analysis. An abductive approach was used to ensure structure and theoretical relevance from the beginning while remaining open to insights suggested by the data. In particular, we resorted to a deductive approach to code capabilities, while an inductive approach to highlight valuable aspects emerged, such as barriers to MaaS adoption for resilience

4. FINDINGS

4.1. MaaS and supply chain resilience

The findings showcase the potential of MaaS to enhance SCR capabilities. All participants agreed on MaaS's overall positive impact, as shown in Table 2. Among the others, E9 stated that MaaS *"is a concept that can certainly increase the resilience of a company."*. E2 strengthened this perspective, arguing that *"MaaS can have an overall impact on resilience when disruptions or unexpected issues arise."* Furthermore, E7 emphasized the role of MaaS in mitigating risks, stating that MaaS *"gives you the possibility to find new solutions (suppliers) when disruption happens."*. While some experts addressed specific resilience capabilities, their contributions also reinforced the broader impact of MaaS on overall SCR.

Considering each resilience capability, participants report a MaaS's positive impact on all the capabilities (see Table 2) except for the collaboration capability – cited just by the professor – and awareness and alertness capability, which is considered not impacted. In this regard, seven participants identified flexibility and velocity as key resilience capabilities enhanced by MaaS.

Table 2. Resilience capabilities and MaaS

	OR	**Flex**	**Vel**	**Vis**	**Red**	**Coll**	**A&A**
E1	+	+					
E2	+	+	+	+			
E3	+						
E4	+						
E5	+						
E6	+		+	+			
E7	+				+		
E8	+						
E9	+	+	+		+		
E10	+				+		
E11	+	+	+	-	-	+	
E12	+	+	+	+	+	-	
E13	+	+	+			-	
E14	+	+			+		
E15	+	+	+				

OR = Overall resilience, Flex = Flexibility; Vel = Velocity; Vis = Visibility; Red = Redundancy; Coll = Collaboration; A&A = Alertness and Awareness

E2, E3 and E13 explained that the impact on flexibility comes from the fact that MaaS gives you access to a wider set of suppliers or a wider set of options to which you can change whenever it is needed. It gives you the ability to adapt the SC to new and unexpected circumstances. Specifically, E13 argued that MaaS enhance flexibility by quickly adapting to changes in demand and disruption events since MaaS is "*a platform where multiple stakeholders can share their requirements, and if there's a match between demand and supply, or if a supplier responds favourably, it enables the company to improve its flexibility in response."*. This is supported by E6, that also adds that MaaS helps to have a view on suppliers' performance so companies can choose which one

fits better according to the needs of better quality, shorter lead times and reduction of costs.

It also enhances velocity, shortening intermediary processes and lead times, thereby enabling faster response to customer needs since resorting to MaaS allows companies to *"get components prepared and shipped, sometimes in less than 24 hours in certain regions"* (E11). Indeed, E13 highlights that his sector is characterised by variable demand, where being fast means *"being able to seize opportunities, generating revenue, and keeping the company alive."*

Moreover, redundancy is also considered a key capability improved by MaaS. E7, E10, E12, and E14 consistently noted that MaaS improves redundancy by allowing the possibility to activate a wider range of suppliers before disruptions, thus reducing reliance on a single source. In this direction, E10 argued that MaaS *"increases redundancy because I can either produce the product myself or have it made by someone else depending on demand."* On the contrary, E11 explained that MaaS was actually born to go against the need of redundancy by avoiding in-house production. This misalignment is due to a difference in the way experts perceive redundancy.

Visibility is another capability impacted by MaaS. E2, E6, and E12 noted that MaaS improves it by providing greater insight into the available production capacity of potential suppliers, particularly during disruptions. In contrast, E11 argued that MaaS reduces the need for visibility, explaining that *"If I rely on MaaS to source my components, I no longer need visibility into my upstream supply chain because I trust the platform's inherent resilience and flexibility."*

Finally, there is no consensus on the impact of MaaS on collaboration. According to some experts, differently from traditional suppliers' contracts where deals, partnerships and joint projects could be established, with MaaS platforms, this type of interaction becomes more difficult to achieve. For instance, E12 states, "*There could be some issues with collaborations since you lose the possibilities of establishing partnerships or joint projects with suppliers*".

Given these results, it is also relevant to highlight that the MaaS's impact depends on the industry and product type. For instance, E13 pointed out that MaaS has a greater effect on resilience in the spare parts industry, where functionality is prioritized over aesthetics. On the contrary, its impact is limited in industries requiring mass production or strict regulatory compliance, as showcased by E5 and E6. Experts claimed that MaaS not only helps to improve overall resilience by impacting several resilience capabilities but also by reducing the cost of risk management and the overall cost of being resilient as E9 highlighted. Also, E10 explained that it can help to improve resilience by reducing the risks associated with investing in increasing infrastructure capacity based on a fluctuating demand. This means that sometimes companies invest in infrastructure to increase supply capacity based on a detected increase in demand that actually could decrease later, so MaaS could reduce the risk that companies face when dealing with this type of decision by giving companies another possibility of acquiring components or products in a MaaS platform or putting their facilities available for producing for MaaS users.

4.2. MaaS implementation barriers

Experts also identified several barriers to effective MaaS implementation. Standardization of products and processes is crucial, as different suppliers may have varying standards, complicating integration. Confidentiality and intellectual property concerns were also common, especially in industries where sensitive information is shared with external providers. Additionally, transaction costs and the need for certifications and homologations present challenges, particularly in sectors with complex compliance requirements.

3 shows that all participants acknowledged the necessity of MaaS in overcoming technological barriers. These barriers include the standardisation of products and processes, data privacy-related concerns, limitations in technological applications, and challenges in the digital representation of products. For example, E14, representing the cosmetics and medical devices sectors, noted that the specific characteristics of their company's products pose significant challenges to the implementation of MaaS. Similarly, E13 observed that MaaS could not be suitable for mass production since, in case of mistakes, the manufacturer could have a standard product with different characteristics, such as a slightly different colour. This is a critical aspect that can occur in dealing with occasional suppliers. Furthermore, E11, a MaaS expert, alongside E5, E9, E12, and E15, highlighted the complexities in ensuring the platform's ability to accurately identify the required product and effectively deliver it to the supplier.

Table 3. Barriers to MaaS

	TB	**EB**	**RB**	**OB**
E8	x		x	
E9	x	x		
E13	x		x	
E15	x			x
E14	x			
E10	x		x	
E12	x	x	x	
E5	x			
E6	x		x	
E11	x	x	x	x
	10	**3**	**6**	**2**

TB = Technological Barriers, EB = Economic Barriers,
RB = Regulatory Barriers, OB = Organizational Barriers

In addition, 60% of the experts identified regulatory barriers, including issues related to confidentiality, homologation of high-quality products, and supplier certification standards. For instance, E10 (from the automotive sector) and E13 (from the white goods sector) emphasized the necessity for all components to be homologated and certified, which presents challenges when sourcing from uncertified suppliers. It is also worth noting that experts categorized under both the technological and regulatory barriers highlighted additional concerns related to intellectual property, as indicated in 3. Specifically, E6, E11, and E12 underscored the risks associated with sharing sensitive information, emphasizing the critical nature of safeguarding intellectual property.

Economic barriers were identified by three experts, with a particular focus on transaction costs and initial investment requirements. E9 and E12 pointed to the potential risk of high

transaction costs, which could also outweigh the benefits of MaaS. Similarly, E11 suggested that purchasing through MaaS may limit the ability to achieve economies of scale, which could otherwise be realized when relying on a trusted supplier.

5. DISCUSSION

MaaS can be a valuable solution for improving SCR. It can support building resilience before the disruption occurs and after it happened. As for the latter, the platform-based nature of MaaS can be leveraged to allow companies to access a wider set of suppliers, while it can allow suppliers to easily access a wider set of customers. This can support SC flexibility. Moreover, the expectation regarding these platforms concerns time reduction to perform purchasing-related activities, i.e. suppliers' scouting and supplier selection, negotiation and contract definition, thus increasing SC velocity. The use of MaaS platforms can be leveraged to test and validate suppliers before the disruption occurs. These results are pretty much aligned with the literature.

Differences with literature emerge when it comes to collaboration. For Tedaldi and Miragliotta (2023), Maas has an impact on collaboration by enabling users to be part of the product design and improving transaction processes. Additionally, E11 explains that collaboration could be seen from the perspectives of the suppliers that unwarily collaborate to create a network that creates value for them and the platform. However, for SC experts this is not the case. They consider that MaaS platforms reduce or annulate collaboration between clients and suppliers. MaaS act as intermediaries between clients and suppliers, allowing companies to have products quicker. Collaboration is mentioned in literature as an important capability for building a resilient SC. Collaboration reduces uncertainty through information exchange (Christopher and Peck, 2004), therefore, it acts before the disruption occurs. While MaaS platforms support SCR after the disruption, literature is scarce in discussing the implications of MaaS on SC visibility, but experts suggest that relying too much on the platform might reduce visibility.

Table 4. MaaS platform functionalities

SC resilience capabilities	**MaaS platform functionalities supporting SCR**
Flexibility	(i) Easy search on well-designed manufacturing and remanufacturing process models; (ii) Easy match-making supporting system; (iii) Wide choice of suppliers; (iv) Clear and transparent suppliers' evaluation track record (KPI)
Velocity	(i) Easy match-making supporting system; (ii) Easy and fast pricing, negotiation and order management; (iii) Easy to integrate with supply chain orchestration models and tools
Visibility	Integrated risks detection and anticipation systems
Redundancy	(i) Easy search based on well-designed manufacturing and remanufacturing process models; (ii) Wide choice of suppliers; (iii) Clear and transparent suppliers' evaluation track record (KPI)
Collaboration	-
Awareness and alertness	Integrated disruption detection and forecast

MaaS's implementation seems to be limited by technological, economic, regulatory and organisational barriers. Products and industries with high standardization levels are perceived by experts as the main candidates for its use to support resilience. The same applies to products in which functionality is more important than aesthetics, e.g., spare parts. In summary, since MaaS implementation is grounded in technological solutions, the results suggest that MaaS supporting systems, to be able to fully support companies in increasing their SCR, need to be equipped with the functionalities presented in Table 4.

The results are based on the understanding and experience of experts about MaaS. The experts see MaaS as a tool to easily assess a wider supply base. However, MaaS can goes beyond multiple supplier of the same good, but it can be used as a lever for having flexible capacity for providing alternative good. Interestingly, this can be a solution in a high impact low probability disruption, e.g., the COVID-19, as highlighted by (Peng et al., 2023) for Product Service Systems. Moreover, the exploitation of MaaS as a lever for the Circular Economy presents a transformative opportunity. MaaS emphasizes the provision of manufacturing capabilities as a service rather than a product. This would lead to innovative business models that that extend product lifecycles, such as remanufacturing and maintenance (Franceschi et al., 2023).

6. CONCLUSIONS

This paper investigates and discusses how MaaS can support SCR, by leveraging on 15 expert interviews. MaaS is a promising solution for allowing servitisation of manufacturing processes. The paper contributes to the literature by linking MaaS to specific SCR capabilities. In particular, MaaS can potentially make SCs more flexible and faster to react after a disruption occurs, but also it can be leveraged to build redundancy. Moreover, this paper contributes to the literature by proposing a preliminary list of potential contexts of application of MaaS for SCR. In fact, MaaS for SCR seems potentially applicable only in sectors with high standardization or where functionality is more relevant than aesthetics. Finally, we draft a list of several barriers hindering the diffusion of MaaS, ranging from economic to technological ones. Our results can also be interesting for managers since the paper provides a reflection on how MaaS technology can be used to build SCR, and suggests a possible list of functionalities to be performed by a potential MaaS platform that aims to be supportive of the SCR capabilities. Results are also relevant to software developers, particularly those offering "platform as a service" solutions, tailoring platforms to address specific needs. The research has some limitations that represent interesting avenues for future research. First the number of experts and sectors involved is limited, secondly the barriers and the functionalities emerged during the data analysis and discussion. Finally, there is a clear need to go further the mere concept of MaaS as a way for finding alternative suppliers for the same product, but research should focus on how leveraging MaaS for alternative purposes.

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