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Impact Pathways: Technology-aided Supply Chain Planning for Resilience

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IMPACT PATHWAYS: TECHNOLOGY-AIDED SUPPLY CHAIN PLANNING FOR RESILIENCE

Abstract

Purpose: Due to emerging uncertainties, supply chain planning (SCP) has become complex for many companies, and practitioners are unsure how emerging technologies can help. We address this gap by identifying pathways of how digital technologies may aid planned flexibility in SCP.

Design/methodology/approach: The research builds on engaged scholarship and co-creation of knowledge. Eight senior managers from two companies participated in three rounds of workshops with us discussing and contrasting their planning challenges and potential solutions using examples of industry 4.0 applications drawn from the literature.

Findings: Based on a novel framework for digital transition in SCP, this research shows how emerging technologies may aid SCP in building resilience to emergent uncertainties and open new research avenues through four impact pathways.

Research Implications: The SCP literature is ruefully short on studies that address technology-aided SC resilience. The research explains why this calls for a paradigm shift in SCP research.

Originality/value: This research argues that resilience-building SCP requires planned flexibility and presents a digital transition framework that allows for it.

Keywords Supply chain planning, Resilience, Digital technologies

Introduction

Emerging technologies have the potential to reduce and simplify the supply chain planning (SCP) complexity and contribute to innovative resilience-building SCP solutions (Jonsson and Holmström, 2016). For example, the shortage of ventilators during the COVID-19 pandemic led to innovative supply chain planning (SCP) in manufacturing to restructure the conventional design and supply and to take advantage of the opportunity presented by 3D printing of components (Liu et al., 2022). In line with Asby's "law of requisite variety"—"variety absorbs variety," novel technologies could help SCP build resilience by offering such new flexibility options to address unforeseen threats and changing consumer preferences. Here, “resilience” is the ability to face

uncertainty from an "open" system perspective that encompasses geopolitical and social factors, and multiple supply tiers. Maintaining “diversity and redundancy" as insurance, "managing connectivity," "being aware of and monitoring change” in systems, "learning and adapting to the changes," and "enabling collaboration and collective actions" are necessary for resilience, either through adaptation ("involves adjusting the existing system in response to an actual or expected change or disruption") or transformation ("involves a more radical and fundamental departure from the existing system in response to changing conditions, threats, or disruptions") (Wieland. et al., 2023). Further, Scholten et al., (2020, p.4) observed, a "narrow focus might neglect opportunities and threats beyond the dyadic relationship [between buyer and its immediate tier one suppliers]...[while] broader focus could, for example, identify the transformation or migration of a risk from one point in the network to another". To react to system-wide disruptions, it is necessary to integrate innovations and changes in the critical areas of the supply chain, for example, in forecasting—the first step of SCP (Browning et al., 2023). Nonetheless, much of the research on resilience focuses exclusively on the organizational level, overlooking supply chains and networks at large (Scholten et al., 2020). Subsequently, the breadth of opportunities for innovations and adjustments across the supply network that emerging technologies may provide in resilience building SCP is ruefully understudied. This gap points to a new paradigm that goes beyond advanced planning tools and analytics to develop dynamic capabilities for "planned flexibility" (Verganti, 1999).

Planned flexibility in the context of SCP could be interpreted as the capacity to anticipate the SC's critical areas early or proactively, at a tactical level, and develop flexibility to trigger reaction measures to manage them during execution, i.e. transforming tactical-level planning problems to operational-level execution. In a similar vein, Peters et al., (2023) observed a need for combined anticipatory and containment strategies at the network level for resilience. Changing tactical

decisions in the middle of execution is costly, and unanticipated reactions might have an effect on sustainability. Crucial data and assurances aren't available until later, which makes tactical decisions also prone to error. New technologies identify and enable tactical decisions that are susceptible to change to be implemented with planned flexibility, while more stable decisions remain more rigid.

There is little knowledge of how emerging technologies can help SCP be resilient. Businesses are now facing such challenges without research-based frameworks and insights. This article serves as a call to action to fill this void and further this new paradigm by empirically identifying pathways and examples of *how digital technologies may aid planned flexibility in SCP in ways that can contribute to resilience under emergent uncertainties.*

Methodology

Two globally competitive and digitally advanced manufacturing companies from electronics and furniture industries (represented by eight senior managers heading production, marketing, procurement, distribution, and management), who, in addition to investing in I4.0 technologies, have been exposed to the escalating demand and supply uncertainties and consequent SCP challenges, participated in three rounds of reflective workshops to develop a shared understanding of how emerging technologies and their applications can affect their respective planning challenges.

The three workshops were organized around specific agendas. At the initial "expression" workshop, the managers shared details on their planning processes, digital strategy and projects, and early impressions of the use of new digital technology in SCP. The case companies encountered challenges that relate to the concerns [1]-[4] observed in the literature (Wieland et al., 2022). This connection between data and literature is shown in Figure 1's Focus 1. From our

theoretical analysis of the workshop data, planned flexibility, which may be largely reliant on five actions (see Figure 1, Focus 2), emerged as a means to build resilience to the aforesaid concerns. Our next step as researchers, inspired by these insights and in preparation of workshop 2, was to find and evaluate myrid research on technology-enabled supply chain applications (identified in the literature spanning production, purchasing, planning, sales and marketing, and distribution) that appeared useful in employing the actions for planned flexibility. Enabling a joint "reflection" with the managers, workshop 2 sought to examine practicality of the identified SC technology applications and their potential implications for SCP in the case settings. This directed us to assess the root causes of the problems and their dependencies (directly or indirectly affecting planning effectiveness), as well as to focus on more specific topics and conduct a second round of search and analysis of the problems expressed and their potential technological solutions before holding a third workshop (Figure 1, Focus 3; linking the I4.0 applications [a]-[h] to enable the needed actions).

Workshop 3 aimed to identify "synergy" in our thinking. The workshop and the subsequent analysis led to the abstraction and categorization of the I4.0 applications for planning to illustrate the impact pathways, resulting in the development of a framework for digital transition in SCP. It revealed that the digital transition in SCP has both adaptive and transformative implications. Adaptive implications, from a technological standpoint, imply that the traditional SCP process is structurally preserved, while automation and intelligent systems replace analogue or routine processes. Conversely, transformative implications demonstrate non-evolutionary processes or product innovation, as well as novel practices that go against the evolutionary status quo. Furthermore, the technology-aided transition may involve the use of new technologies, either directly in planning activities (i.e., to facilitate) or indirectly (i.e., to empower), to make SC activities more efficient, better integrated with other processes, or even creating new and innovative alternatives that

structurally transform traditional processes or activities, which may improve reactively and proactively dealing with uncertainties. The analysis expands on the categorization of I4.0 applications [a]-[h] based on their adaptive or transformative capabilities to facilitate or empower SCP, as shown in Focus 4 of Figure 1. The process of analysis entailed "reading between the lines" and "interpreting silences" (Poland & Pederso, 1998), particularly drawing on the companies' tacit, automatic, and spontaneous "knowing in practice" and "reflection in actions". The workshop-based shared learning method revealed a new paradigm for technology-aided SCP research by combining managers' experiential knowledge of planning problems, contextual barriers, and views on solutions with our critical thinking, literature associations, and interpretive analysis.

The framework is illustrated with case examples in the following sections.

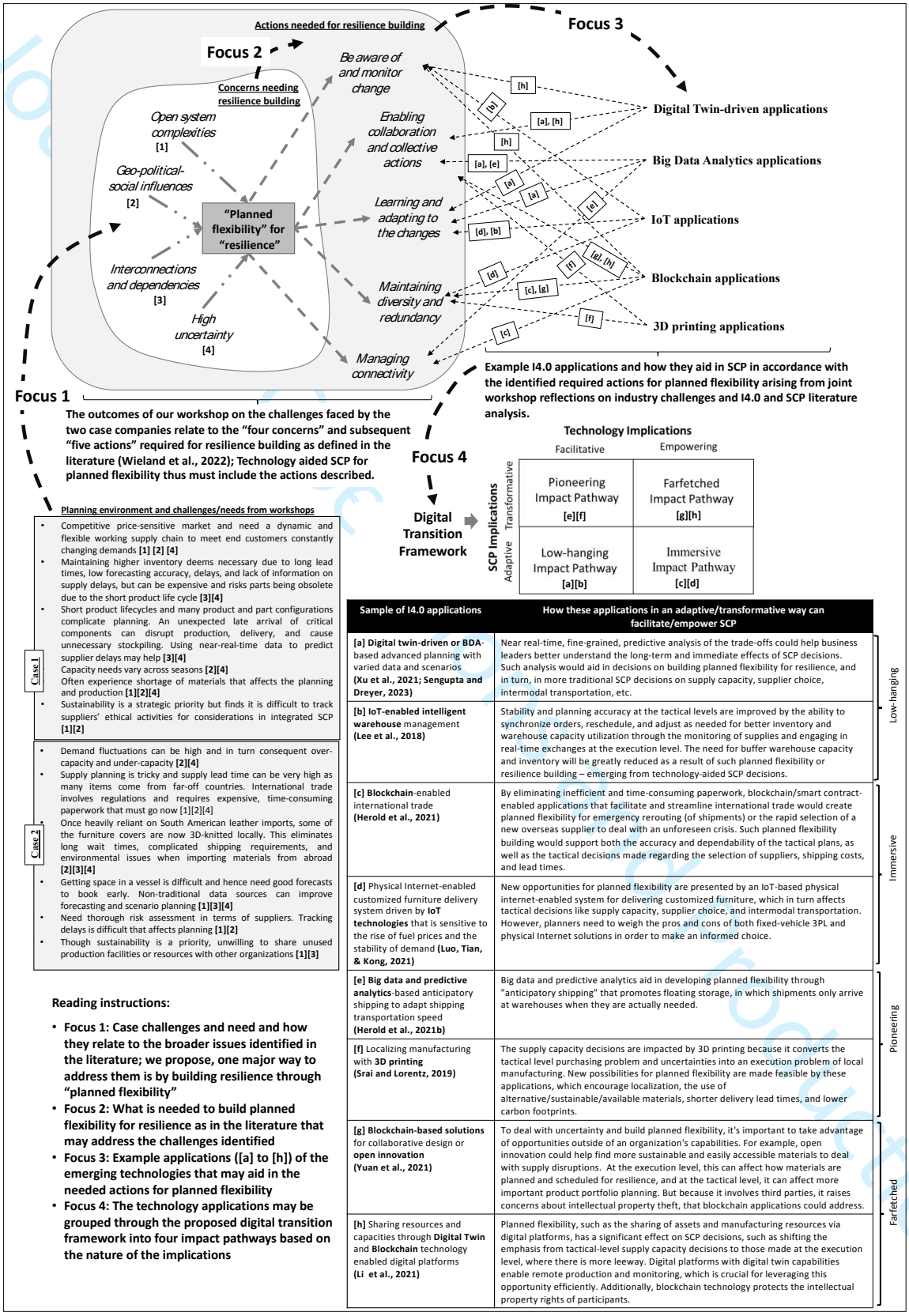

Figure 1: Workshop-led illustration of how I4.0 technologies can support "planned flexibility"

Illustrating the transition framework-led pathways to a new SCP research paradigm

Impact pathway 1: Seizing the low-hanging opportunities for planned flexibility

Low-hanging represents the impact pathway to an evolutionary/adaptive SCP transition by developing digital capabilities that directly support traditional SCP activities or resilience-building decisions. Participants in Case 2 agreed that data sources like product life cycle, product in-use, market growth rate, repeat purchases, and generational substitution could improve their forecasting and scenario planning. What-if simulation, constraint-based planning, integral planning, and optimization could be enhanced by big data analytics applications (Xu and Pero, 2023) or digital twin-driven planning (Sengupta and Dreyer, 2023) to achieve tactical convergence based on execution level changes. Case 1 has established a "digital value chain" for direct customer ordering through their web portal, emphasizing customer integration for effective planning. A blockchain-enabled customer order management system, using the developed analytical capabilities is an example of further improving the efficiency of the demand-supply process (Martinez et al., 2019) - reducing the number of operations, the time of orders in the system, and workload with traceability and visibility of orders and SC participants.

We found in our workshops that the case companies have heavily invested in digitalizing manufacturing but have not linked this to SCP. Before a company can deploy the planned flexibility, it must first understand the synergies between its existing digital capabilities. More research is needed to determine how SCP can leverage digital manufacturing capabilities without additional investments or transition efforts. Therefore, "Less for More" research with an "inside the box" mindset along the low-hanging impact pathway is crucial. Emerging technologies can enable advanced SCP activities or intervention processes like S&OP and contribute to evolutionary path discussions (Danese et al., 2018), advanced planning systems, and big data analytics adoption (Xu and Pero, 2023). While new technologies and planning processes are already known and in

use, this impact pathway will open new lines of inquiry at the intersection of the two, to shed light on implementation, utilization, generative mechanisms and outcome (intended and unintended).

Impact pathway 2: Immersive exploration for indirectly enabling planned flexibility

Immersive represents the impact pathway to an evolutionary/adaptive SCP transition by developing digital capabilities that indirectly support traditional SCP activities or decisions for resilience building (empowering role of technologies). For instance, international trade barriers and cumbersome paperwork could be eliminated with the help of blockchain applications (Herold et al., 2021). Such applications can allow for the speedy, eco-efficient rerouting of shipments through greener routes in unexpected events, like Suez C anal stop due to stranded ship. These could, for example, streamline Case 2's time-consuming paperwork for international trade via smart contracts to address issues like longer lead times or execution crises without affecting tactical plans. Sustainability is a concern in both Cases 1 and 2, and both could benefit from such planned flexibility. Although not related to SCP, such digital initiatives can improve planning effectiveness.

A common misconception we observed is that technology-aided planning often focuses on software and analytics. SCP needs advanced analytics, but its success depends on its flexibility in creating options in the face of market and supply turbulence. New technologies offer indirect opportunities for planned flexibility that businesses should take advantage of. Thus, research along the immersive impact pathway that is "Other than Core" is needed. For greater confidence in the plans, SCP researchers need to evaluate how technology can help with not just planning and optimization, but also the creation of flexible capabilities and dynamic resources. Technology has almost only been used in SCP research to aid communication and decision-making (Jonsson et al.,

2021; Sengupta and Dreyer, 2023) and rarely enables planned flexibility, even though it can reveal new ways to handle uncertainty/disruption and spur "out-of-the-box" thinking.

Impact pathway 3: Pioneering the creation of new planned flexibility options

The pioneering impact pathway drives a non-evolutionary/transformative SCP transition by developing digital capabilities that directly support resilience-building SCP decisions. Importing supplies such as leather for furniture covers from far-off countries can result in long lead times and uncertainties. Case 2 now 3D knits furniture covers in Europe instead of importing South American leather. 3D printing may help localization, which affects SCP. Importing supplies is a major source of delay, lead time, shipping requirements, and sustainability issues that plague modern planning, but a digital transition could help circumvent such problems with a new design or product, albeit by reimagining or transforming conventional processes.

Companies often feel compelled to face all SCP challenges head-on to maintain productivity. However, there may be ways to avoid them altogether by finding alternatives like switching shortage materials or localizing manufacturing to avoid delays. In addition to developing ways to address existing problems, companies should also investigate technologies aimed at preventing them. Emerging technologies can improve capacity, logistics, and sustainability through new solutions. This makes "New for More" research, which is emphasized along the Pioneering impact pathway crucial. SCP research should look into novel approaches (or avenues for planned flexibility) that proactively address such underlying planning problems. For instance, building designs that use fewer scarce materials can make planning easier, requiring more research into how technologies facilitate such alternatives and how they affect planning effectiveness and efficiency.

Impact pathway 4: Envisioning farfetched indirect opportunities for planned flexibility

Farfetched represents the impact pathway to a non-evolutionary/transformative SCP transition by developing digital capabilities that indirectly support transforming the SCP activities or decisions for resilience building (i.e. *empowering* role of technologies). For instance, for efficiency and safety reasons, the cases are hesitant to share unused manufacturing resources with external organizations despite capacity issues. However, our workshops indicated a Blockchain-based digital twin-sharing platform that supports that production collaboration (Li et al. 2021) could address their concerns. Blockchain technology protects participants' intellectual property, while digital twins enable remote production and monitoring on a single platform. Companies can better utilize capacity and reduce wasteful buffering by sharing resources. Such an application would play an indirect, empowering role in building planned flexibility to deal with growing uncertainties.

Our workshops revealed that companies can wrongly assume that in-house resources and capabilities are the sole determinants of SCP success. However, more than just internal capability development is needed to make the most of emerging technologies. Cooperation, coordination, and coopetition between related or unrelated businesses may create new flexibility opportunities. Technologies should enable companies to operate in/build ecosystems that indirectly support SCP and resilience. Thus, the farfetched impact pathway calls for "more than ever" attention to ecosystem opportunities, open systems, and coordinated activities enabled by new digital technologies for planned flexibility.

Conclusions and contributions

The digital transition framework presented in this research emphasizes the significance of inside-and-outside-the-box thinking by examining technologies in SCP through both facilitative and empowering lenses and employing them for the adaptation and transformation of SCP activities.

The framework highlights the present emphasis on emerging analytics and intelligence capabilities in SCP research as a "low-hanging" starting point for digital transition. Further, the framework exposes with suitable examples, the "immersive," "pioneering," and "farfetched" opportunities to explore the untapped potential of new technologies in resilience building SCP by enabling planned flexibility. This serves as a call to mid-range theory building by providing a metatheoretical account of technology-enabled SCP that accommodates the dominant resource-focused theories, such as the resource-based view and dynamic capabilities theory for planning efficiency, as well as the less explored innovation and behavioral theories, to outline how past decisions, path dependencies, perceptions, or thought worlds may affect disruptive innovation and process transformation.

For practitioners, our findings provide insights into how even seemingly disconnected SC digitalization activities may have an impact on SCP, and point to the changing role of SC planners as strategists building planned flexibility, which is all too often overlooked. Strategic digitalization initiatives can benefit from adhering to the proposed digital transition framework, which advocates for the systemic adoption of a company-specific combination of digital capabilities spanning the four impact pathways. Figure 2 summarises needs, focuses, and exemplifies research questions of the four pathways.

	Impact Pathway 1 **Seizing the low-hanging opportunities for planned flexibility**	Impact Pathway 2 **Immersive exploration for indirectly enabling planned flexibility**	Impact Pathway 3 **Pioneering the creation of new planned flexibility options**	Impact Pathway 4 **Envisioning farfetched indirect opportunities for planned flexibility**
Need emerging from the pathways	In the minds of many, SCP is separate from the digitalization of manufacturing facilities. In order to build or deploy planned flexibility, companies need to understand the synergies between SCP and their existing digital capabilities in manufacturing.	While SCP benefits from analytics capabilities, the plans' effectiveness also depends on planned flexibility in the face of persistent uncertainty. Companies must recognize the indirect opportunities for planned flexibility afforded by emerging technologies to ensure effective execution.	It may be possible to avoid certain SCP challenges by switching to alternative resources such as switching the materials/components that is under shortage or localizing manufacturing to avoid delays; however, this calls for reimagining traditional processes or adopting new approaches.	Companies should go beyond developing internal capabilities to take advantage of emerging technologies in SCP. With the new technologies, the SCP process can be transformed, for instance, to share critical resources and data with other companies or engage in cooperative competition by building and leveraging open, ecosystems for planned flexibility.
Focus of the pathways	Researching "**Less for More"** opportunities, with a focus on how existing digital manufacturing technologies or investing in tools can improve outcome of existing SCP activities – from an "inside the box" perspective	Researching "**Other than Core**" opportunities with a focus on how technology can help with not only direct planning and control activities but also the creation of infrastructure (flexibility and dynamic resources) for planned 'integrated planning and execution'.	Researching "**New for More**" opportunities with a focus on how alternative solutions could change the very nature of the existing problems – as in addressing supply delays of materials/components by innovating through designs, that contain more readily available materials/components.	Researching "**More than Ever**" on the ecosystem opportunities and coordinated activities enabled by new digital technologies is needed to ensure long-term viability and stability – this would require out-of-the-box solutions, open innovation, breaking out of the path dependencies, and may be a coopetition mindset.
Examples of future research directions in SCP	1. What digital capabilities do manufacturing companies have or can accumulate, acquire, or divest that serve as the foundation for planned flexibility? 2. What new planning (human/competence) capabilities are needed to leverage the digital capabilities? 3. How could digital capabilities support the interlinkages between strategy and tactical and execution level SCP? 4. What are the mechanisms that underpin analytics-based interventions (for instance, digital twin or big data analytics) for varied forms of planned flexibility, and what is the impact on performance?	1. What digital capability building could indirectly affect SCP activities to increase planned flexibility? 2. How may the scope of SCP be broadened/developed with the indirect digital capabilities (for instance, near real-time access to supply and demand data or use of smart contracts in international trade and negotiations), and how may this require new planning (human/competence) capabilities? 3. How may the new forms of digital capabilities and innovation complement the direct capabilities supporting the interlinkages between strategy and tactical and execution level SCP? How does this lead to a multi-level SCP set-up? 4. What are the mechanisms that underpin an indirect intervention (for instance, blockchain and smart contracts that enable prompt paperwork/international agreements, information sharing to support crisis rerouting of shipments) for varied forms of planned flexibility, and what is the impact on performance?	1. What, and how may new forms of digital capabilities in SCP (such as reconsidering design to avail more available supplies, localizing supply with 3D printing, or analytics-driven anticipatory shipping for effectiveness) contribute to building planned flexibility? 2. What organizational capabilities is needed to reimagine, adapt, or transform the SCP process (for instance, addressing the path dependencies, or conflicting thought words among the leadership and planners)? 3. How may the new forms of digital capabilities and innovation for planned flexibility in SCP affect the traditional SCP activities? 4. What are the mechanisms that underpin new form of technology interventions (for instance 'localization interventions like 3D printing) for varied forms of planned flexibility, and what is the impact on performance?	1. How can new forms of digital capabilities enable open ecosystems for enhanced cooperation and transparency that can indirectly influence innovation and transforming SCP activities for planned flexibility? 2. How can the new opportunities for planned flexibility stemming from digital capabilities enabling open ecosystems broaden the scope of SCP or change the traditional SCP process? What organizational capabilities are required to accomplish this? 3. How might the interlinkages between strategy and tactical and execution level SCP be affected for SCP in open ecosystems? 4. What are the mechanisms that underpin an indirect intervention that calls for a transformation of the SCP process (for instance digital twin and blockchain-enabled shared manufacturing platform) for varied forms of planned flexibility, and what is the impact on performance?

Figure 2: Research along the Impact Pathways

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Appendix 1: Description of the participants

Cases	Industry	Position/Responsibility of the participating managers	Workshop 1	Workshop 2	Workshop 3
Case 1	Electronics industry	Chief Executive Officer	☑	☑	☑
		Manager, Purchasing and Logistics	☑	☑	☑
		Manager, Production	☑	☑	
		Director, Sales and Marketing	☑	☑	
Case 2	Furniture industry	Technical Head	☑	☑	☑
		Manager, Logistics planning	☑	☑	
		Manager, Production Planning, Customer Service	☑	☑	
		Manager, Sourcing and Supply	☑		

Appendix 2: Workshop quotes supporting Case 1 and Case 2's "planning environment and challenges/needs" (Focus 1, in Figure 1)

Quotes from Workshop 1 and 2	Synthesis
Case 1	
"I also think it's a capacity challenge and a price challenge because our product is also looked from a high price pressure now." *"Goal is to have a dynamic and flexible working supply chain to meet the end customers' constantly changing demands."* *"More or less a rule is we get unexpected orders from customers so this is extremely difficult and of course much of the customers have no clue what they agree to delivering the next coming month because they are also outselling things."*	Competitive price-sensitive market and need a dynamic and flexibly working supply chain to meet end customers' constantly changing demands.
"The electronic market is late say compared to [say] automotive industry and is very unpredictable because we do not have long term orders on the same product. There are a lot of revisions and lot of small changes that apply very often. So, it is very difficult for us. It is more or less impossible to manufacture finished goods and put in the stock because that product could be old before we can sell it." *"The long-term orders are the most important thing we have. Order for more than one year is the only thing to do. Too much stock of course is not good… and is very costly …but yes, we do keep more at stock…These days with lead times from 4 weeks to 1 and half years, forecasting is very critical."* *"Products can go obsolete: we get commitments from the customer, and we commit for the components. So, the risk for us is that they don't need it in May next year, maybe they need it in September next year. Then we will have components and raw material at stock for 3-4 months. I think that's the biggest risk for us."* *"Some customers are pretty good at predicting and sending us forecasts and we also have customer on the other end, who, so to speak, are not able to give us any forecasts at all, and half of the time the forecast shared is wrong."* *"Customers always are optimistic, and to prevent to have too much inventory, we from time to time just don't agree with the forecasts from customer."* *"The problem as I see is that we don't develop our own products we are a blueprint manufacturer of our customers' products and that means that we do not have insights into the market that we maybe should have. But it is more or less impossible to have as well because the customers don't have that. It's difficult for also for them to predict because the innovation activities in the electronic market, especially, for the telecom market customers, is very high. Thus, things change very fast."* *"We get frame orders from customers. That's the binding order. That is going to cover the number of months, typically then 4 to 6 months coverage, that's not enough at the moment. So, we are constantly on our customers to try to place orders for a longer time"* *"Well of course we measure the suppliers on delivery performance, and also the delivery time, and lead time, but it is impossible in these days where the delivery time change almost everyday."* *"We are not able to get any lead times estimate before we actually place the order. So, that is a problem, and we are trying to plan it with the customers. You don't know where you are going to place the order in the system before you actually have ordered parts and got feedback from the suppliers back. Then you can set the date, but that is not the way to do it right. And then we have cancellation allocation and so forth and so this is nightmare."*	Maintaining higher inventory deems necessary due to long lead times, low forecasting accuracy, shortages, and delays, but can be expensive, and risks parts being obsolete due to the short product life cycle.

"Many of our customers have a large part of innovation for their production. So, the lifecycle of actually quite many of our products are quite short then". *"They [customers] can get orders for 10 units or 100 and they don't know the configurations because several customers have units that can be configured into 50 or 100 variations with several different boards. So, the combination of the boards, the configuration of both the software and the hardware is tremendous. There is no way that they are able to figure that out."* *"Now it's the second of June, and if you ask me what we are going to ship this month, I will probably miss by 10-15 million in maybe a 50 million turnover; it is really difficult to be sure of what we are going to ship this month and that's this month we are in. It depends on the material situation and what the customers need."* *"We need improvement in planning systems of course, because we got here a very complex picture of what we are going through. We have 50 active customers, hundreds of different boards, mechanical assemblies going through every week, and thousands of parts that are hopefully in stock or on its way for stock, or we don't know, or is unconfirmed, or is postponed, or have an have a no actually."*	Short product lifecycles and many product and part configurations complicate planning. An unexpected late arrival of critical components can disrupt production, delivery, and cause unnecessary stockpiling. Using near real-time data to predict supplier delays may help.
"We have production in the seasons as well, so we are in trouble in some parts of the year."	Capacity needs vary across seasons.
"We have huge increase [in turnover] coming on, so it's actually looking pretty good if it wasn't for the problems with the material. Our headache as we have mentioned several times is that we have a huge problem because we don't know when we get the last part in. So it is very difficult. Of course, we will try to decide what we are going to put into the machines next week, and the week ahead, but that very difficult. So, we have planning meetings."	Often experience shortage of materials that affects the planning and production.
"We have great focus on sustainability. End customers also have that." *"We are working with the sustainability goals. We have focus on that and is also a part of our strategic plans."* *"It is extremely difficult to track suppliers, their production process, their carbon footprints, but we try to do this also in cooperation with the customers because they specify the parts we are going to use. So, in the end, they have the responsibility. But we try to do that all the time. We have been ISO certified factory since a few years back with 4001."*	Sustainability is a strategic priority but find difficult to track suppliers' ethical activities for considerations in integrated SCP.
"The last year, should we say, the last ten months we had under capacity based on the demand from the market, and have increased our delivery times. We have orders for ten weeks in our system today, but the normal is three weeks. [on the contrary] last year we had the order horizon for two weeks, and we struggled to fill the factory, and we had to reduce the capacity in the factories. So it is very very fluctuating."	Demand fluctuations can be high in turn consequent over capacity and under capacity.
Case 2	
"Need better planning." *"We are forecasting at a high level. So, to a purchasing manager it will give an indication but of course, he will have to estimate and think on how much we will have to purchase going forward… Let's say sales numbers: we know how many square meters of*	Supply planning is tricky and supply lead time can be very high as many items come from far-off countries.

leathers and fabrics and aluminium parts and components we would need to secure for the next 12 months, that is every month, for the next 12 months. Typically, most of our components when it comes to metals, electronics and mechanisms that we are using are very often produced in Asia. It's very typical to calculate like 4 to 6 months total lead time. But, as we speak, this picture is very very different. It is taking super long lead time now which we took into consideration one year ago saying that we were facing very volatile times. So, we made decision based on the overall planning process to secure enough materials in case the demand will increase." *"Outside of Norway we have 4 factories, and we have distribution centers that will do what you call pack to order or even final assembly process. So, we have like not a perfect but a pretty good distribution of the value chain towards regional customers. Nonetheless, furniture industry is not volume driven as the car industry; we cannot have too many sources of components. It's not easy to localize all components due to the volume. We need to see the economies of scale before we can duplicate a process".* *"We have import containers which we cannot get released before we get the original bill of lading. We have our own port here at the factory, we have the container at the port, but we cannot open it and get the goods out before we get the customs released… Too much of paperwork and regulations are involved [in international trade]. Norwegian logistics suppliers are still using papers, fax, and phone, and e-mail. Change is needed that may be driven by the logistics suppliers, the big ones."*	International trade involves regulations and requires expensive, time-consuming paperwork that must go now.
"We are doing kind of 3D printing when it comes to sewing the [furniture] covers [as an alternative to those using imported leather]. We call it 3D knitting; [it reduces waste] where you don't cut the textile, but you knit the whole cover…we think we are first movers in furniture industry doing that in a big scale… This may also address the shipping capacity, planning, lead time, or the sustainability issues."	Once heavily reliant on South American leather imports, some of the furniture overs are now 3D knitted locally. This eliminates long waiting times, complicated shipping requirements, and environmental issues when importing materials from abroad.
"Of course, there are delays and there we see lead times increasing, and also, I guess you have to be lucky now to get space on vessels. Of course, we need to provide a good forecast and an early forecast to our vendors and forwarders." *"Have an online channel where you sell directly to customers, and this will of course give you better information about the sales through this channel. We are ready for it. It is a very very small part of our business today. It is close to nothing because customers prefer still to shop in shops."* *"We have google analytics when it comes to how many users are looking up on (and) configuring our products out there in each market, and we do a lot of statistics, I mean we have statistics back to 1934 when it comes to sales development, which kind of products are the ones surviving for decades etc."* *"We can think of sensor-based sofas for in-use data."* *"Yes, we got like manual report say that repeat sales is strong or good or maybe missing. But that is not like a data driven process. Maybe, they know it when they submit the purchase order, but then it's too late. There is no such thing through which we can read the activity in the shops, like what you indicated."*	Getting space in a vessel is difficult and hence need good forecasts to book early. Non-traditional data sources can improve forecasting and scenario planning.
"Of course we see a big risk for vendors shutting down due to either covid or side effects coming from covid. So, we are running this risk assessment for quite some time as a result, now it's exactly one year ago when the team was told to expect much longer	Need thorough risk assessment in terms of suppliers. Tracking delays is difficult that affects planning.

lead times. We need to book transportation, I think, eight weeks ahead. And thanks to some of the market intelligence flowing in now and followed by risk assessment, we pretty much survived the last year." *"Now we are not able to track if the delay is caused by the vendor of the materials or the logistics provider or what the delay is caused by."* *"We need to plan accordingly and not put into the production plan because we will get a shortage of the raw material for example."*	
"Sustainability is not something that we have been using as it is now, but we are seeing it more and more coming. Also, we see now that for ocean freight, for example, you can book more sustainable solutions and also sustainable schedule and routes, of course, with longer lead times." *"The data we will have when we go live with our new order management system, we will have more insights into these [the sustainability trade-offs]."* *We don't consider too much the way we can share resources with other companies, and we don't produce [or indulge in shared manufacturing]… [but] yes, we do have a limited production of components as the other industry peers, but not to extent that we must share [resources] of with others."* *"[Post covid, today] we cannot produce enough to meet the demand …[We] share the unique resources from each of our plants… [but] we don't consider too much the way we can share resources with other companies."*	Though sustainability is a priority, unwilling to share unused production facilities or resources with other organizations.

Appendix 3: Workshop quotes and synthesis spanning Focuses 2 and 3 in Figure 1, leading to the impact pathways as Focus 4.

Impact pathway 1: Seizing the low-hanging opportunities for planned flexibility		
Exploration through Workshops 1 and 2		**Joint reflections and synthesis from Workshop 3**
Quotes	Opportunities and overview	Outcome/actions needed
[Case 1: A] *"We have developed our own electronic manufacturing system …This is something we work with and call it our digital value chain. We try to integrate the customer; they have their own website that they can log in to and look into our systems and they will find their order status etc. available to them via this website. It involves a lot of automatic order handling.* **[Case 1: B]** "*We have also done a lot of integration with other commercial systems like Odoo."* **[Case 1: C]** "*We have made some integration also with shipping companies like DHL and FedEx."* **[Case 1: D]** *"My personal view is that the problem today is the data. It doesn't help with any new sophisticated system as long as we don't have the data from the suppliers in the system… It is challenging as suppliers [may] have their own agenda… [but] the suppliers that survive in the future probably will have to share more data….[we need to] be able to integrate that with "freedata " and other developers we have."* **[Case 1: E]** *"We sit and plan and talk to customers to have a complete picture of the situation, and more often we don't see scenarios to be honest… in a normal situation we could predict what we could get of raw materials; it would be interesting to make different scenarios so to produce in a more efficient way."* **[Case 1: F]** *"We are building up the digital twin (DT) not necessarily for the planning system now, but we have introduced DT in our factory. It is for the production flow. But we will move to planning later – Digital twins can help. The big struggle now is in seeing an*	• Accessing new sources of near-real time data and having the flexibility to adapt by digitally integrating with suppliers and customers will be promising with the emerging technologies. ***[Supporting quotes: Case 1: A, B, C, D, G and Case 2: A, B, C, E, F]*** • Have already invested in digital solutions like digital twin, digital value systems, purchasing tools, order management and warehouse management systems, etc., but not able to utilize the generated data/intelligence in SC planning and control. ***[Supporting quotes: Case 1: A, C, F, G and Case 2: C, D, E, G]*** • Advanced planning and scenario analysis capability is needed. ***[Supporting quotes: Case 1: E, F, G and Case 2: E, H]*** Interpreting the silences and reading between the lines • While the two case companies have invested in digitalization, the efforts are not linked with SCP. These already made investments can serve as a major	There is a potential for accessing information through new (or unconventional) sources of data with new technologies and build planned flexibility by being able to see and process them for action in near real time. The digital technologies can, for example, facilitate building planned flexibility: i. by enabling a collection of relevant data from myriad (often new) sources (that helps in "*being aware and monitoring changes"*) - Linking investments in advanced sensor technologies, integration systems, or IoTs, such as IoT enabled-warehouse management systems (Lee et al., 2018) with planning systems is one such way forward, making most of the ongoing digitalization projects. ii. by enabling reactive, predictive, and prescriptive actions from advanced scenario and trade-off analysis (i.e. "*learning and adapting to changes"*, through digitally enabled "*collaboration and collective actions*") - Linking ongoing projects in digital twins and analytics with planning systems might help achieve tactical convergence based on execution level adjustments (Sengupta and Dreyer, 2023; Xu et al., 2021).

improvement in supplies – while we are able to get the long-awaited chips, now we have a capacity problem internally to plan and get through the production – moreover, the customers want the delivery as early as possible, as they too have been long waiting. Digital twins could have helped us to see this coming and plan for it… It [Digital twin] definitely will help in capacity planning." **[Case 1: G]** *"We have a lot of historical data, and also a lot of data all over, and also we have purchasing tools that is also used for information to actually track the availability of components and also lead times, so we have discussed if this [data] could be an opportunity; it could be useful and have actually been on the plan to work on, but it's quite complex [to use]…[In addition to the purchasing tools], we use spektra as our own MPS, we have our own app with budget and forecast that gets updated regularly; that is something that will end up in our dashboard – We have live Power BI dashboard."* **[Case 2: A]** *"We can think of advanced sensor-based sofas for in-use data. We can say that yes it will be the case. But I think that we are talking about the sensor technology for at least [when] things begin to evolve more."* **[Case 2: B]** **"***We have not managed to integrate in a very good way the cultural aspect and the understanding of the whole process let us say the total company's resource planning platform…In most countries there is a lot of state managed statistics that is kept updated on a regular basis and its relatively easier to link up to all those systems. We can also purchase the same information meaning to see like on a macro level, let us say how is the furniture marketing developing in the United States as otherwise very often we develop our opinion on what is written in the newspaper. We could do much more of such integration."* **[Case 2: C]** *"We use google analytics and see for example, a tremendous growth in the interest of our products, but we don't systematize this information in a way [that] we can utilize this [in planning]."*	source for generating data from a variety of new sources, and to aid in capabilities for effective planning and planned flexibility. This suggests the need for focussing on the existing investments to get more out of it. • A lack of understanding on the synergy between new technologies and their potential in traditional SCP to cope with rising uncertainties is evident, along with a lack of focus and vision for digitally enabled SCP.	

[Case 2: D] *"We are working on implementing an order management system with our biggest vendor for logistics on ocean freight. So, our vendor will then see all our purchase orders and material vendors at an early stage, and they would see what is going to be booked on the containers in the future…Also, with the order management system, we will get data when each process in the procurement or all stages in the procurement process has been covered; there is a purchasing order, that order has been received, the booking of transportation has been done to meet like a lead time information, then we get automatic variation from the plan, so you can say that we will know much early that there is a delay."* **[Case 2: E]** *"We would like to go into more technology, we have many sources [of data] today that we do not utilize. We are not capable at the time being to combine all those sources."* **[Case 2: F]** *"We need to do the Inventory counting a lot of times to fix this 'soldor' (Stock). If there is a digital system that really could work, it would be gold for us."* **[Case 2: G]** *"We are now going into warehouse management systems that is totally integrated with the ERP systems. The IoT based warehouse management system is the next level for us. It will be perfect, but we are not close to that today."* **[Case 2: H]** "*This [i.e BDA based demand planning and fulfillment] will be relevant for us because today we say oh, it's spring we will sell less, oh it's soon Christmas we will sell more, it's like that. So we need we need this in the future and there is a huge amount of information about our sales. So, I think this will be integrated into our planning systems sooner or later."*		

Impact pathway 2: Immersive exploration for indirectly enabling planned flexibility		
Exploration through Workshops 1 and 2		**Joint reflections and synthesis from Workshop 3**
Quotes **[Case 1: H]** *"We use silicon expert platform solutions [that helps us in] product life cycle management".* **[Case 1: I]** *"I know the blockchain technology is useful [in tracing materials], but is 4-5 years ahead I think, at least that's my opinion…It is extremely difficult to track suppliers, their production process, their carbon footprints, but we try to do this also in cooperation with the customers because they specify the parts we are going to use, so in the end they have the responsibility but we try to do that all the time. We have focus on this all the time. But Silicon expert platform solutions does the job."* **[Case 2: G]** *"It is not something that we have been using as of now, but we are seeing it more and more coming and also, we see now that for ocean freight for example you can book more sustainable solutions and also sustainable schedule and routes of course with longer lead times".* **[Case 2: H]** *The data we will have when we go live with our new order management system, we will have more insights into this sustainability and fuel-efficient route information.* **[Case 2: I]** *Implemented biofuel truck transportation [that requires mid-route switching of two trailers and journey sharing], electric distribution trucks. [This is] a start (of being) 100% carbon free… We have a lot of initiatives that we have now started to communicate as you can see that on our website both for transportation as well as energy that we utilize in the factories which vessels etc. and then we will have the data available for the carbon footprint.*	Opportunities and overview • Ability to effectively integrate with the suppliers and customers. ***[Supporting quotes: Case 1: H, I, C and Case 2: D]*** • Sustainability is a concern, and flexibilities in shipping for eco-efficiency along with resilience, or for sustainable schedules and routes will be crucial in the future. ***[Supporting quotes: Case 1: H, I and Case 2: D, H, G, I]*** • International trade barriers and cumbersome paperwork should be eliminated which causes delays, increases lead times, and reduces decision flexibility; this has an indirect effect on SCP. ***[Supporting quotes: Case 2: J, K]*** Interpreting the silences and reading between the lines • There is a misconception that the role of technology in planning is limited to the core analytics capabilities.	Outcome and actions needed There is a potential for digital technologies to bring about new supply chain processes that can aid in engaging with customers or suppliers, or are less cumbersome than traditional ones, and which can then serve as infrastructure solutions/dynamic resources to activate new and sustainable flexibility options that can be considered in resilience building SCP. The digital technologies can empower building planned flexibility by unfolding opportunities beyond core planning activities in SCP, for example: - Blockchain technology and smart contracts, can reduce the inefficiencies in international trade (Herold, et al., 2021), making it easier and faster to make changes to supply and shipment plans, and accessing more flexibility options for consideration in planning. Therefore, indirectly, it serves in "*managing connectivity*" for "*maintaining diversity and redundancy as insurance*". - A physical internet-enabled customized furniture delivery system that relies on IoT technologies may provide efficient and sustainable flexibility options for resource planning (Luo, Tian, and Kong, 2021). This requires traditional operations to

[Case 2: J] *"Too much of paperwork and regulations are involved [in international trade]. Norwegian logistics suppliers are still using papers, fax, and phone, and e-mail. Change is needed that may be driven by the logistics suppliers, the big ones…. [Also], we have import containers which we cannot or get not released before we get the original bill of lading. We have our own port here at the factory, we have the container at the port, but we cannot open it and get the goods out before we get the customs released.* [Also], *shipping inefficiencies in letter of credit mechanisms and the extensive customs paper work etc. leads to excessive time consumption and delays."* **[Case 2: K]** *"I guess this [blockchain based solution for international trade] will be driven by the logistics suppliers, the big ones. No small manufacturer in Norway, can do this by themselves."*	• Building new flexibility options is an overseen opportunity in technology-aided SCP and needs more attention.	be transformed to a set of physical internet-enabled smart logistics facilities to support the physical internet decision support platform. Therefore, indirectly such technologies can serve in "*learning and adapting to changes"* and building *"diversity and redundancy as insurance".*
Impact pathway 3: Pioneering the creation of new planned flexibility options		
Exploration through Workshops 1 and 2		**Joint reflections and synthesis from Workshop 3**
Quotes	Opportunities and overview	Outcome and actions needed
[Case 2: L] *"We can say that most of our suppliers are not so advanced remember that we are buying, I think our biggest category is leather (which) is coming from suppliers in Brazil. It is a very fragmented industry, very used to face to face meetings [less digitally integrated]."* **[Case 2: M]** *"We are doing kind of 3D printing when it comes to sewing the [furniture] covers. We call it 3D knitting; [it reduces waste] where you don't cut the textile, but you knit the whole cover. So, we need just the minimum of working minutes per chair, and you don't need a sewing machine or operators and you can also in future in the next coming years, can offer customers much more adapted*	• Companies can avoid concerns about digitally integrating with less developed suppliers for monitoring and managing delays, high lead times, and sustainability issues by using alternate processes, materials, or localizing manufacturing. ***[Supporting quotes: Case 2: L, M, N, O]*** • While technologies such as 3D printing is being invested in for	There is opportunity to reimagine/revisit the processes, design, or materials that make SC planning complex in order to replace them with technology-aided alternatives that avoid the complexity and stabilize planning effectiveness. The digital technologies can facilitate enabling new alternatives that can transform the nature of the SC problems:

patterns. They can have their names on the backside of the chair and so on." **[Case 2: N]** *"There will be a lot of possibilities in the future [with 3D printing in furniture industry]… may also address the shipping capacity, planning, lead time, or the sustainability issues [that are regularly encountered]".* **[Case 2: O]** *"We can say that most of our suppliers are not so advanced remember that we are buying, I think our biggest category is leather (which) is coming from suppliers in Brazil. It is a very fragmented industry very used to face to face meetings like you talked about the future."* **[Case 2: P]** *"Transport has to be booked much ahead, and delay in the delivery of any single component can cause a problem [in getting the product ready for shipment by the booked time]. Vessel availability can be an issue and can cause delay in delivery. Need to book early, share forecasts."* **[Case 2: Q]** *"We have google analytics when it comes to how many users are looking up on (and) configuring our products out there in each market."* **[Case 1: J]** *"We buy what we call the PCB's. That's the green board that we assemble all the parts on. So, we have a global supply chain; we are ordering the PCB's for instance from China, and other parts of Asia, and all the other stuffs around globally … [3D printing] is not being considered at the moment to replace this, as it is not cheap. 3D printing is very useful in making tools and fixtures - that is a huge advantage [as it increases the flexibility of production], but making an actual product we can sell, no, not in a while."*	sustainable and flexible manufacturing, prototyping, and tooling, its implications in SC planning or affordability/returns are not yet well looked into. ***[Supporting quotes: Case 2: M, N and Case 1: J]*** • Uncertainties in supplies affect scheduled shipments and order fulfilment; advanced analytics aid in gauging customer behaviour and interests for predicting demand. ***[Supporting quotes: Case 2: P, Q]*** <u>Interpreting the silences and reading between the lines</u> • There is a tendency to perceive of technology-aided solutions only to solve complex SC problems than finding smart alternative ways to change the very nature of the problem or simply bypassing them. • Given the limitations of early booking of vessels for availability, the possibility of accurately anticipating customer demands using predictive analytics (google analytics) very early and planning the shipment in anticipation of the demand for customer service levels and order fulfilment need more attention.	i. The complex global SC planning problem can be transformed to a local execution problem. For example, - The uncertainties associated with importing materials from far-off countries can be mitigated by localizing manufacturing. 3D printing of products for localization (Srai and Lorentz, 2019), such as, 3D knitting of furniture covers locally where the furniture is being manufactured, allows for addressing the dependencies and uncertainties of importing materials (such as leather from South America), which is also more environmentally friendly. Such options simplify a complicated SC problem (transforming it into an internal capability and capacity problem) and lessen the need for deep SC *"collaborations and collective actions"*, as well as "*maintaining diversity and redundancy"* for resilience. ii. The flexibility of proactive planning and shipping based on demand anticipation can help alleviate the planning challenges of last-minute changes or disruptions that impact shipment schedules, fulfilling delivery due dates, and service levels. - Anticipatory shipping, which promotes the flexibility of floating storage through big data and predictive analytics (Herold et al., 2021b), as well as *"collaboration and collective actions"* with logistics providers and *"managing connectivity"* with customers (through Google, social media analytics, etc.), allows for reimagining SCP for customer order fulfilment and

<table>
<tr><td></td><td></td><td>maintaining high service levels under uncertainties.</td></tr>
<tr><td colspan="3">Impact pathway 4: Envisioning farfetched indirect opportunities for planned flexibility</td></tr>
<tr><td colspan="2"><u>Exploration through Workshops 1 and 2</u></td><td><u>Joint reflections and synthesis from Workshop 3</u></td></tr>
<tr><td><u>Quotes</u>

[Case 2: R] “We are a society within a society we utilize and share the unique resources from each of our plants, and we do a lot of let’s say component production in one side and we do assembly on another plant. We have several products that are produced simultaneously in a few plants closer to customers etc. Situation today though is completely opposite. We cannot produce enough to meet the demand. We don’t consider too much the way we can share resources with other companies, and we don’t produce [or indulge in shared manufacturing].”

[Case 1: K] “We are in trouble in some parts of the year, so we have to lower staff then and also in some areas through small capacity…Some of our products are related to the summer and spring season and some other in winter time so yeah its quite difficult [to manage capacity].”

[Case 1: L] “We haven't looked into that [sharing economy models]; do we have a plan for that, not yet…We like to have a strategy to do everything locally; as long as we have financial muscles to invest in new equipment and increase in capacity at the factory, we will do that… I think there is a very strong competition between the manufacturers in Norway, so, no one then wants to share anything. I think that is then a general challenge of course, and we also know that our competitors, they have established manufacturing units also abroad to increase their own capacity. So, its quite a problem.”

[Case 2: S] “Blockchain and digital twin enabled sharing platform for shared manufacturing, is far from where we are today. We are at such a basic level on this. We need to start to digitalize the product data management system. We need to improve that as a start, and</td><td><u>Opportunities and overview</u>

• Sharing within the organization, across the many factories is prevalent and acknowledged. [Supporting quote: Case 2: R]

• Insecure of being involved in sharing manufacturing resources with other companies although there are capacity challenges that affect planning and they might gain from sharing. [Supporting quotes: Case 2: R and Case 1: K, L, M]

• Being at the early stages of digitalization, opportunities emerging from digital twin and blockchain enabled sharing platforms are still far in the future. [Supporting quote: Case 2: S]

<u>Interpreting the silences and reading between the lines</u>

• There is a tendency of limiting possibilities to the four walls of the organizations and not seeking opportunities beyond, and through building collaborative ecosystems for</td><td><u>Outcome and actions needed</u>

There is the potential for digital technologies to empower transformative SCP by enabling processes that otherwise comes forth as barriers to some of the disruptive opportunities that the new technologies reveal.

This might involve, more than ever, leveraging ecosystem opportunities through the new technologies in ways such as:

- Supporting collaborative design through open innovation that might lead to building alternative products or processes that are non-conventional and in a way emerge as new ways to circumvent SCP complexities tied to the traditional means. Open innovation through collaboration poses IP violation threats, that might be overcome with Blockchain technology (Yuan et al., 2021).

- Shared manufacturing is an opportunity arising from new technologies, with obvious implications for SCP in terms of capacity and flexibility. Nonetheless, securely and efficiently sharing manufacturing resources (for "being aware of and monitoring changes" and "enabling collaboration and collective actions") would gain from digital</td></tr>
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also digital twin is a little bit in the future… and then blockchain-based digital twin is even longer in the future. And then shared manufacturing with the external companies is also in the future of us." **[Case 1: M]** *"[In this industry] it is very easy for our customer to switch to another competitor. So, that is also a challenge lets say we cooperate with another competitor in Norway, it's very easy for the customer to move the product to that manufacturer. That may be one reason for not asking for more capacity at a competitor even if there are needs."*	resilience or engaging in open innovation. • There is a lack of clarity regarding the potential of new technologies to enable the sharing economy while ensuring trust in collaboration and efficient remote monitoring and control. Though such opportunities are fairly far from current practice, they warrant research attention.	twin and blockchain enabled digital platforms (Li et al., 2021).