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Resilience in Supply and Demand Networks

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Abstract: The present era is characterised by many events that have influences on supply chains and supply networks. This concerns, e.g., war, epidemics, natural disasters, accidents, strikes, political instability, and political sanctions. These are generally grouped under the term "disruption". In order to avoid the risk of supply chain disruption, major disruption of supply networks, or loss of customers associated with disruptions, it is necessary to take preventive and proactive measures in supply chain management in terms of planning. This paper is intended to briefly summarise the current state of knowledge with the most important facts and derive a new definition from it. In addition, an analogy to maintenance is established for the first time. In doing so, a comparison of the concepts and a listing of the important proactive measures derived from them for increasing resilience are made. In the course of this, the field of action considered is extended from the exchange of suppliers through the entire supply chain network to the exchange of customers.

Keywords: supply chain resilience; risk management; resilient supply chain strategies; maintenance; supply network; demand network

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1. Introduction

In an increasingly volatile world, networks that are resilient turn out to be the most successful [1,2]. Disruptive events are increasingly challenging global supply chains that were previously focused on efficiency and leanness. Proactive and reactive measures and capabilities must be applied in a way that allows organisations to react agilely and flexibly to potential risks.

In addition to new risks that arise—for example, due to climate change, political tensions, and shortages of raw materials—opportunities always arise in times of crisis, too. As threatening as disruptions can seem for global supply networks in this context, new opportunities can also emerge from the new orientations. Disruptions in the sense of new opportunities are primarily customer-market-oriented and have a major impact on supply networks. While the term supply network (SN) or supply chain (SC) implies that developments are downstream, i.e., from the supplier to the end customer, the reality is different with regard to the opportunity-related effects and possibilities for supply networks. In order to clarify the two-sidedness of the orientation of these networks, the term supply and demand networks (SDNs) seems more suitable. In the following, this term will be used synonymously with supply chains or supply networks.

Due to the topicality of the subject and the increasing importance of resilience for companies, this paper aims to help transfer and possibly bundle resilience efforts in other areas of a company, such as maintenance, and, thereby, to extend the resilience considerations of a company to an entire SDN, as suggested by Kamalahmadi and Parast [3]. Until now, the transferability of risk measures from risk management areas has been considered difficult [4]. Our approach is to show the parallels, and these can be used to form synergies and to learn from or transfer this established methodological knowledge.

Within this paper, the theoretical considerations are to be approached from two sides:

(1) In the authors' view, agility is an important basis for new solutions. It generally characterises the ability of a company to realign its business model and organisation. Transferred to the supply chain network, this applies analogously to the broader area of the entire structure and process organisation of the SC, including the selection and connection of customers and stakeholders of all kinds.
(2) A supply chain network is a complex organisational system. Complex technical systems are generally treated via maintenance and risk management. This particularly applies to technical assets and infrastructure with a special need for security. It is, therefore, obvious to unify tasks, strategies, solutions, integrations, and lessons learned from the areas of both technology and organisation within the framework of basic research.

2. Materials and Methods

This research is based on an analysis of new scientific publications and of the authors' own scientific projects with reference to resilience, SCM, and logistics. Furthermore, many years of scientific work and practical experience in the areas of logistics and supply chain management serve as a basis for additional insight. The scientific task at this point is to generate an overview of the knowledge in this field. In general, three different fields of action for increasing resilience can be described: (cf. also [5])

(a) Robustness/stability = measures to increase resilience
(b) Flexibility = measures to quickly evade disruptions
(c) Crisis management = measures to respond to a disruption in the best possible way (proactive = creating conditions for good crisis management; reactive = disruption elimination, disruption mitigation, and disruption compensation measures).

The body of literature considered here includes some suggestions for achieving SC resilience, as listed in Table 1.

Table 1. Summary of ways to achieve SC resilience in accordance with [6].

Author	How to Make an SC Resilient
Brandon-Jones et al. [2014] [7]	-By creating robustness
Blackhurst et al. [2005] [8]	Quickly recognising the problem, developing an appropriate recovery plan, and redesigning the SC to ensure resilience
Lee [2004] [9]	Realising agility, adaptability, and alignment (Triple A)
Lee [2004] [9], Pettit et al. [2010] [10], Hohenstein et al. [2015] [11]	Through flexibility, visibility, and collaboration
Jüttner [2011] [12]	SC decision-making and application processes need to be very fast
Pettit [2010] [10]	Learning from experiences with crises
Cao [2010] [13]	Common goals
Pettit et al. [2013] [14]	Information sharing
Min [2019] [15]	Transparency through use of technology (blockchain)
Modgil et al. [2022] [16]	AI-facilitated supply chains
Mubarik et al. [2022] [17]	Intellectual capital and SC learning

Resilience refers primarily to risks that are largely unknown and can pose a significant threat. Table 2 contains important risk examples based on Biedermann [18] (p. 164 ff). To ensure competitiveness, a supply chain must be able to respond to these risks. These can be divided into different levels depending on their origins. Biedermann [18] classified

them into three categories: environment, supply chain, and company. Environmental risks refer to risks that lie outside the sphere of influence of a supply chain, such as social, political, or natural risks. What all of these have in common is the difficulty of forecasting and, accordingly, of reacting and preparing for this risk class. Recent crises, such as the coronavirus pandemic, have shown how extensive and drastic the effects of this risk class are on the existence of supply chains and entire business models.

The risks of the supply chain risk class are in the more direct range of influence. These relate, for example, to the nature of the network or procurement strategies. In times of digitalisation, however, IT systems in particular should also be mentioned in this context. Systemic process support is sometimes essential for the functionality of processes, particularly at interfaces in the supply chain; therefore, there is an elementary risk that these could fail, be manipulated, etc.

Last but not least, the company risk class comprises risks that are located at the company level and, thus, primarily affect individual supply chain entities. These can sometimes have immense effects on the rest of the supply chain, which is known as the ripple effect [19].

The term proactivity is understood to mean acting proactively on the basis of anticipated future events with the aim of both deliberately bringing about a desired situation and avoiding an undesired one [20]. In the context of SC risk management, it should be emphasised that undesirable events (e.g., natural disasters) often cannot be avoided. Proactive measures are needed to absorb the impact and maintain performance [21]. This is why it is crucial to the competitiveness of an SDN to identify the correct measures and strategies for achieving resilience.

Table 2. Risk examples (supplemented based on Biedermann [18], p.164 ff.)

Risk Class	Risk Drivers	Risk Example
Environment	External environmental risks	**Natural disasters** (severe weather, avalanches, floods, hurricanes, forest fires, volcanic eruptions, earthquakes, etc.)
		Technical disasters (explosions, fires, building collapses, traffic accidents, radioactive accidents, accidents, etc.)
		Political risks (Legislation, political instability, war, terror, embargoes, political sanctions, etc.)
		Social risks(famine, epidemics and pandemics, damage to reputation and image, etc.)
		Financial risks (currency risk, market risk, risks from derivatives, securities and foreign exchange, default, liquidity and credit risk, inflation, extreme price increases, etc.)
	Industry-specific risks	Labor strikes
		(short-term, major) fluctuations in demand
		Customer payment defaults
		Resource scarcity (e.g. chip shortage)

Table 2. *Cont.*

Risk Class	Risk Drivers	Risk Example
Supply Chain	Network structure-specific risks	Network complexity, large propagation of interference
		Single sourcing
		Bullwhip effect
		Transport damage and delays
		IT failure (systems, software)
	Partner and interface-specific risks	Outsourcing
		Partner default and insolvency (e.g. supplier, producer, service provider)
		Low partner quality (e.g. supplier , producer, service provider)
		Unavailability of qualified personnel
		IT-infrastructure and security risks
Companies	Company-specific risks	Company mergers
		Low resource efficiency
		Capacitive overload (Logistics and production)
		Inaccurate demand forecasts and poor information sharing of POS data
		Storaging and capital costs

Blue = complements to the original.

3. Results

3.1. Defining Supply Chain Resilience

The term "resilience" originates from psychology and is increasingly being applied to other circumstances mutatis mutandis. A detailed discussion of the term can also be found, for example, in [5,6]. Resilience generally characterises pronounced resilience and the ability to recover, combined with learning to cope with crises. Three definitions are listed as representative for this:

> ISO 22316:2017-3 defines resilience as follows: "Organisational resilience is the ability of an organisation to absorb and adapt in a changing environment to enable it to deliver its objectives and to survive and prosper [22]".
>
> Hohenstein et al. (2015) defined supply chain resilience as follows: "Supply chain resilience is the supply chain's ability to be prepared for unexpected risk events, responding and recovering quickly to potential disruptions to return to its original situation or grow by moving to a new, more desirable state in order to increase customer service, market share and financial performance [11]."
>
> Biedermann (2019, p. 49) defined supply chain resilience as: "the adaptive ability of a supply chain to prepare for unpredictable events, respond to disruptions, and return to the desired level of performance through the continuous execution of business processes, with the goal of increasing the performance and competitiveness of a supply chain [18]."

The following criticisms can be noted on the existing definitions of the term:

1. The enumerated definitions focus exclusively on risks. The same view of unpredictable events should generally also apply to opportunities and requirements that threaten existence or expand it. Disruptive opportunities and requirements of recent times were, for example, the procurement of medical FFP2 masks, which included their production and distribution, as well as the establishment of vaccine supply chains for the COVID-19 vaccine. Here, supply chains that no longer existed had to be restored as quickly as possible or new supply networks had to be planned and implemented under great time pressure.

2. The listed definitions lack the characteristic of learning, which can take place both in humans (traditionally, IT-supported) and with the use of artificial intelligence.
3. The response to a major and unexpected deviation can be recovery (the repair of the existing supply chain, adjusted planning and controls/regulations), as well as, for example, a partial redesign or a complete redesign.

This is why the authors suggest the following as a new definition:

The resilience of a supply chain as an organisational system is the ability to be well prepared for unexpected, disruptive events (disruptive risks that threaten existence, as well as emerging market chances or opportunities), to react to them quickly and in a targeted manner, and to both survive and thrive. At the same time, learning from coping with a disruptive event should further qualify the staff and the organisation.

Lasch [23] and Sheffi et al. [24] developed the phase model of SC resilience (see Figure 1), which describes the course of performance in the event of a disruptive event. Starting from the current state, the readiness phase decides how the further development of the performance will evolve in relation to time. In the original model, a disruptive event, e.g., a natural disaster or the loss of a central supplier, is followed by a loss of performance. Depending on the readiness, this may be larger or smaller. The impact of this drop in performance is defined as resilience, i.e., how far it deviates from the reference base. This is followed in the recovery phase by an increase in the performance curve due to measures taken to compensate for the cuts in the supply chain—for example, by switching to an alternative supplier. In the final section of the curve, compensation for the cuts takes place, which may result in a performance level below the reference baseline, a return to it, or an improvement in the baseline compared to the reference baseline.

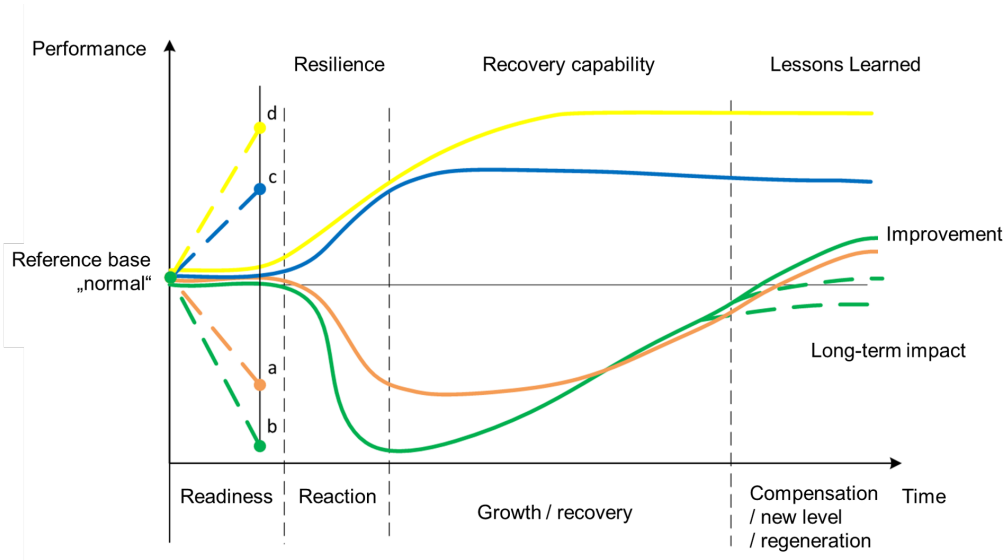

Figure 1. Extended phase model of SC resilience based on [23] (p. 310) and [24] (p. 42).

In the course of the previous argumentation—that, in terms of supply chain resilience, not only risks but also opportunities and possibilities can be reacted to—this concept and graphic were supplemented in the upper part by the analogy of the process when a market opportunity arises. An organisation such as a supply chain—or a supply and demand network—can also be resilient in the sense of being responsive to new opportunities. In this context, this means, above all, being flexible enough to increase its own competitiveness when an opportunity arises by seizing it and embedding it in the organisation. In this case, the performance curve is greatly increased when an opportunity arises, e.g., by discovering new customer needs and meeting them, thus directly reflecting a strong demand as a first mover on the market. In the recovery capability phase, the task is

then to transfer these new services or products, for example, into the standard business process flow. In the phase of lessons learned, the knowledge gained is then anchored in the organisation, thus improving future resilience. Considering lessons learned is equally essential when considering resilience in the risk sense. A central point of the development of an organisation's resilience lies in its ability to learn from disruptive events and, thus, to positively influence all phases of the resilience model in the long term by shortening the phases or influencing the course of the performance curve in such a way that it leads to fewer performance losses or to a higher performance gain.

During the research, a broad terminology that is related to supply chain resilience was found. Still, there is no coherent understanding of the concept of resilience and the referenced terms [18]. As a result, a clustering of the terms associated with supply chain resilience, as well as a categorisation thereof, can be found in Figure 2.

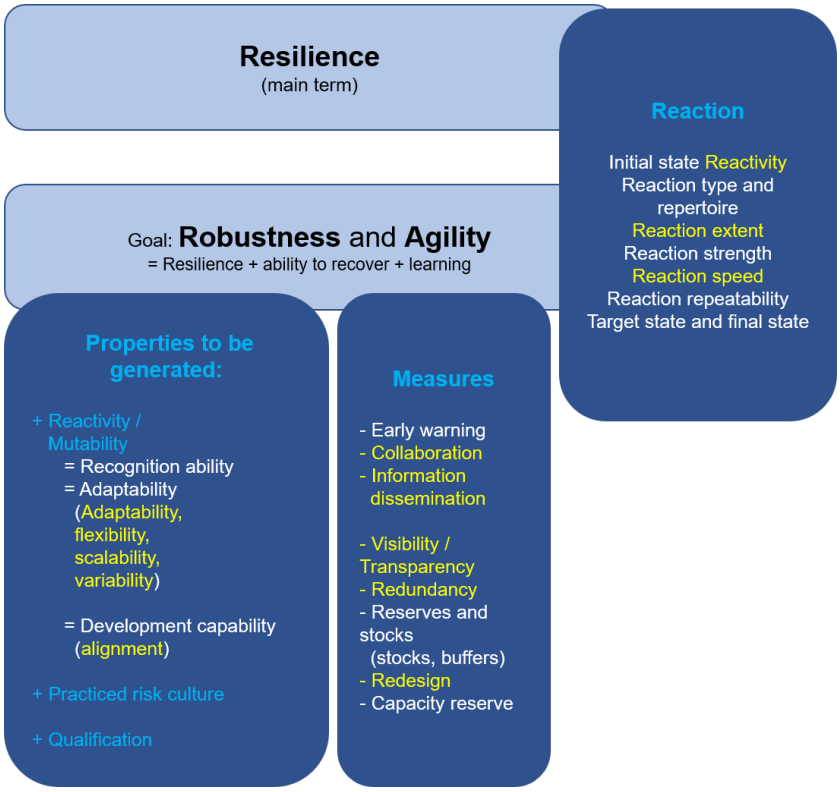

Figure 2. Summary and clustering of resilience-related terms and concepts.

For the classification of the terms associated with resilience, a categorisation into goals, characteristics, measures, and reactions emerged. Accordingly, resilience can be divided into the two target dimensions of robustness and agility. This results in characteristics that a resilient network should have, such as reactivity, adaptivity, a practiced risk culture, and qualifications. The inclusion of opportunities in resilience thinking brings agility to the forefront of goal setting. While robustness focuses on maintaining or returning to a previous or slightly better state, agility opens up the possibility of moving to a completely different and potentially better state. Given the rapidly changing environment in which supply and demand networks must exist, the authors see agility in particular as a success factor.
Furthermore, measures for achieving these characteristics or goals can be derived. Depending on the goal, this may entail, for example, setting up early warning systems, increasing the transparency of the network, or building redundancies. Ultimately, the form of resilient effectiveness can be measured by using the "response" dimension. A check of the speed of the response and the difference between the target state and the initial state are possible variables that can be used to make a statement about the quality of resilience.

3.2. A Comparison with and Learning from Maintenance

An underlying literature search of the open-source publications in the Science Direct database on supply chains, resilience, and maintenance revealed that, to date, the transferability of strategies from maintenance has not yet been researched. In this context, maintenance is seen in the literature only, for example, as a measurement in order to achieve resilience [25], as part of tactical planning, where the aspect of resilience should be considered as well [26], or as a cost point in the evaluation of the supply chain resilience costs that are considered [27]. Publications addressing both supply chain resilience and maintenance strategies were not found.

Maintenance has technologically complex systems as its objects of observation. These can include individual machines, a sequential chain of machines, or entire production networks. Individual entities in this system have parameters that are influential on their functionality and, thus, in sum, influence the functionality of the overall system. Supply and demand networks can be viewed in a similar way. They also consist of individual entities—companies—and can be viewed as a supply chain or as an entire network [1], as illustrated in Figure 3. Both systems have in common that the goal must be to ensure or increase the resilience of the entirety through individual components that are as resilient as possible.

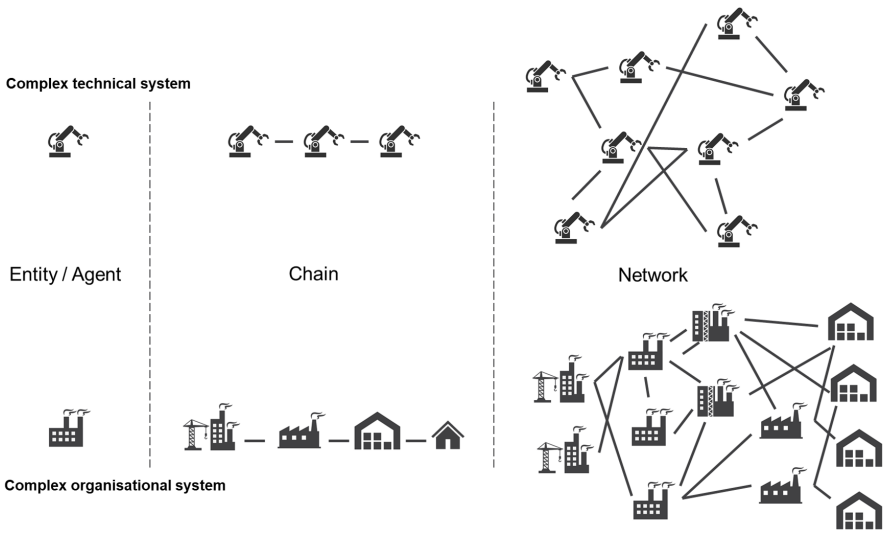

Figure 3. Complex technical and organisational systems—entity, chain, and network.

For this reason, the basic concepts of maintenance are explained and then applied in tabular form (see Table 3) to the application area of supply and demand networks in terms of their transferability.

In many areas, the methods and approaches used to maintain a technical system can be transferred to an organisational system, such as an SDN. Referring to inspection, key performance indicators, early warning systems, or checks could be used to monitor SDNs in terms of their status. At regular intervals, when servicing is carried out on technical systems, it can also be checked in the SDN, for example, whether barriers exist in communication or in the processes at interfaces or whether safety stocks are sufficiently dimensioned. In the area of repair, both reactive and proactive measures could be taken, such as stocking spare parts at critical points in the network. The application of the principle of continuous improvement from the philosophy of maintenance to an SDN could be done, for example, through the proactive replacement of supply chain modules. Moreover, a continuously conducted vulnerability analysis can help identify the potential for improvement. What has not yet been considered in the scope of maintenance, but must be considered, in principle,

for resilience, is improvement in the sense of a complete restructuring of an SDN and the higher-level control and regulation of system thinking, e.g., of a PPS at the SDN level.

The following description of the essential principles of maintenance is based on the work of Ryll [28], as well as DIN EN 13306:2017 and DIN 31015:2019 [22]. In particular, the preventive maintenance strategies of interest for considerations of resilience will be briefly discussed below. In addition to (complex) technical systems, the considerations should also be explicitly transferred to (complex) organisational systems, such as supply and demand networks. This concerns both the "normal organisation" and the optional organisation in exceptional cases, and this is to be kept potentially operational. Maintenance of a technology (ensuring latent functional readiness), maintenance of an organisation (ensuring latent functional readiness), and risk management (specifically organisation) thus form a meaningful unit.

Table 3. Comparison of maintenance strategies with supply and demand network implications

Tasks of Maintenance (Complex Technical Systems)	Brief Characteristics of the Contents	Transfer to SDN (Complex Organisational Systems)
Inspection (monitoring)	Methods and tools of technical diagnostics (human, sensor technology)	• Controlling • KPIs • Early warning systems • Checks • Forecasts
Servicing	Maintaining the functional efficiency and the target state	• Maintaining the organization through information, communication, coordination • Review and test use of alternatives • Verification of safety stocks • Maintenance of early warning systems
Repair	Active creation of the target state	• Reactive measures (fast, effective) • Proactive measures (plans, spare parts, personnel, tools, tests)
Improvement	Measures within the framework of the existing system = Kaizen measures	• Proactive measures (e.g. replace modules, supply network components)
Analysis of weaknesses	Identification of potential problem areas	• Proactive measures (e.g. replace modules, supply network components)
Not part of the classic maintenance is the improvement in a greater sense	Network redesign and process reengineering	Network redesign and reengineering of the supply network
Not part of classical maintenance is the PPS and SCM		Control and regulation (use of planning, scheduling and disturbance control)

Preventive maintenance (condition-based): Here, the use of methods and tools of technical diagnostics takes place. There are different possibilities to choose from: pn the one hand, manual monitoring and control through regular inspections with the aim of recording and evaluating condition-relevant parameters. Alternatively, condition monitoring systems (CMSs) independently carry out inspections (cyclically or continuously). The aim is, on the one hand, to monitor a maximum of components with as few sensors as possible in order to keep investment costs low and, on the other, to avoid introducing new, additional fault options into the system to be maintained. Application: Condition-based maintenance is suitable if a change in the wear stock is both measurable and economically justifiable. It becomes possible to detect damage in good time, to predict the occurrence of damage, and, thus, to prevent it. This secures the functioning of technology and organisation if required (e.g., testing of the alarm systems and processes of an organisation or the provision of manual alternatives in the case of power and IT failure) [28].

Preventive predictive maintenance: The further development of a condition-based approach is a predictive maintenance strategy [29,30], which sets in even earlier. The goal is to detect faults that are already hidden and to prevent their further development in a targeted manner. The starting point here is the definition of functions and possible malfunctions, e.g., according to the following classification—safety-relevant, environment-relevant, operation-relevant, and operation-independent malfunctions [28]:

- Safety-relevant malfunctions are damage patterns that lead to impairments of plant safety and occupational safety (safety-relevant). Examples include accident hazards, fire or explosion hazards, the potential collapse of buildings and infrastructure, or hazards from electricity.
- Environmentally relevant malfunctions are damage patterns that violate environmental protection regulations. These include, for example, the exceeding of emission limits, leaks, noise emissions, and the release of hazardous substances.
- Operationally relevant malfunctions cause a (serious) functional restriction or a failure/standstill of a system through the deterioration of availability. This requires identification of the equipment, components, assemblies, or elements causing the failure. The same applies to damage patterns that affect product and/or service quality.
- Operation-independent damage patterns have no relation to operation and only cause repair costs. These damages may be important as a source of loss if they occur frequently.

4. Discussion and Limitations

Supply chain resilience is still a relatively young field of research [18]. The need for companies to align themselves resiliently in order to survive in a volatile world in the future is constantly growing, which is why there is great potential for research on resilience in SDNs. The conclusions and concepts addressed in this paper are limited by the scope of the literature included and the authors' wealth of experience. As an extension, it would be useful to include literature from other language areas, as well as an extended group of experts—for example, by applying the Delphi method.

Additionally, another research method could be used. The method applied in this paper was a logical, theoretical derivation. This should be supported with practical evidence. Especially against the background of the high practical relevance, case studies dealing with the resilience of SDNs in relation to emerging opportunities would be a particularly useful contribution to further knowledge and could be used as a practical verification and validation of the results found.

Moreover, the research area lacks a decision-making system for better practical applicability, which should be applied when a company wants to decide whether it should rather emphasise an agile or robust design of its network—or in what proportion—when shaping its own resilience.

As also listed in this paper, some work on supply chain risk has already been published. There are many overlapping concepts, such as risk management, disaster management, crisis management, and change management, which have different addressees in their considerations, but should basically show overlaps in their methodologies. Another research direction could be to investigate the possibility of merging these research areas.

As mentioned, focusing only on risks is a one-sided view of resilience. Opportunities also constitute a dimension of impacts on SDNs and require an agile organisation. As also listed within this paper, there are already classifications for risks. Extending this consideration and categorisation to include opportunities could be a useful addition that was not handled within the scope of this paper.

5. Conclusions

In this paper, some new and modified ideas are presented and discussed.

A new, expanded definition of resilience is presented and proposed, and it explicitly includes opportunities. This corresponds to the usual division of an environment into opportunities and risks, as has been known and proven for many years in environmental analysis and models, such as TOWS and SWOT. Opportunities that are not perceived can also be critical if they are not perceived by an SDN itself but by others; thus, they can threaten the existence and success of the SDN. Furthermore, by naming the term "opportunity", the intent is also to positively screen the environment and imply a cultural reorientation in a proactive and agile rather than a protective manner. A subsumption of positive deviations and opportunities into the term "risk" according to DIN ISO 31000:2018 in the sense of a "positive deviation from the expected" does not do sufficient justice to the current social and economic developments and requirements in the view of the authors. The explicit use of the term "opportunity" is, therefore, suggested. In addition, the learning of an organisation is emphasised as a necessity for resilience.
Furthermore, there is a more precise name for the object of study, with a change from a supply chain and supply network to "supply and demand network".

The terms frequently discussed with resilience are clustered. Thus, in addition to the otherwise typical substantive descriptions, a conceptual system for generating overview knowledge is presented for scientific discussion.

For the first time, a transfer of strategies and methods from maintenance to maintain the functionality of complex technical systems is extended to the observation space of SDNs as complex organisational systems. As a consequence, a suitable integration of attention to the maintenance of technology and organisation in terms of normal and exceptional situations, as well as opportunities, into risk management is proposed.

The following research questions were formulated and form the basis for further research:

1. How can resilience-relevant opportunities be suitably revealed and characterised (e.g., with a morphological box)?
2. How can maintenance methodologies be transferred to complex organisational systems and suitably modified and utilised to both meet current and future requirements for SDNs?
3. How should the maintenance of technology and the maintenance of organisations be integrated into opportunity/risk management in the age of Industry 4.0/Industry 5.0?
4. How can opportunity, risk, crisis, and disaster management be integrated into SDNs in order to be able to use synergistic effects?

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Abbreviations

The following abbreviations are used in this manuscript:

CMS	Control Monitoring Systems
SC	Supply Chain
SCM	Supply Chain Management
SDN	Supply and Demand Networks
SN	Supply Network
SWOT	Analysis of Strength, Weaknesses, Opportunities, and Threats
TOWS	Analysis of Threats, Opportunities, Weaknesses, and Strengths

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