# Operationalizing supply-side resilience: Toward a cost-effectiveness analysis of managerial practices addressing disruptive threats for buyers in manufacturing companies

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برای مادرم و خواهرم

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### Appendix A



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# List of abbreviations

| | |
|---|---|
| ABC | Activity-based costing |
| CT | Contingency theory |
| DCV | Dynamic capabilities view |
| EBITDA | Earnings before interest, tax, debt, and amortization |
| KPI | Key performance indicator |
| MC | Manufacturing company |
| MOE | Measure of effectiveness |
| PBV | Practice-based view |
| PSM | Purchasing and supply management |
| RBV | Resource-based view |
| RESPIRE | Resilience practice recommendation system |
| SC | Supply chain |
| SCDM | Supply chain disruption management |
| SCEM | Supply chain event management |
| SCM | Supply chain management |
| SCRM | Supply chain risk management |
| SSRES | Supply-side resilience |

# Summary

Unexpected supply disruptions originating in upstream supply chains (SCs) and escalating downstream have cost manufacturing companies (MCs) billions of Swiss francs in potential revenue over the past few years. Current risk management methods contain too many statistical limitations to address these risks, thus supply-side resilience (SSRES) has become a topic of strategic importance for MCs. While MCs are currently under pressure to find the right managerial practices to build their resilience capabilities, their buyers often have difficulties grasping the concept. This incomprehension leads to a lack of understanding of which practices to adopt and how much these practices cost. While research on resilience is proliferating, it is generally fragmented and provides no holistic view of SSRES practices with the possibility of conducting pragmatic CEAs.

The present research aims to develop a method to operationalize SSRES through: (1) conceptualizing, (2) measuring the effectiveness of practices, and (3) measuring the cost of practices. The practice-based view (PBV), contingency theory (CT), and rational choice theory (RCT) are applied as theoretical lenses for the investigations. The research comprises one purely qualitative and two mixed methods studies devoted to one operationalization component each. The first study, on the conceptualization of SSRES, entails a comparative case study design with six cases. The second study, on effectiveness measurement of SSRES practices, incorporates a systematic literature review and a case study. The third study, on cost measurement of SSRES practices, draws on a general case study design with five cases. A synthesis integrates the methods for an adaptable CEA concept.

The results provide (1) a concept of SSRES including contingency variables and a catalog of relevant practices, (2) guidance for effectiveness measurement with specific KPIs, and (3) guidance on how to estimate the cost of practices. The dissertation culminates in the development of RESPIRE, a versatile practice recommendation system based on the methods and results of the first three studies.

The RESPIRE system equips decision-makers to not only better understand SSRES, but also to manage and control the practices continuously. Thereby, this dissertation helps to address the dearth of empirical research on SSRES practices and guides MCs in developing resilience management strategies.

# Zusammenfassung

Das zunehmende Auftreten von unerwarteten Lieferunterbrechungen, die ihren Ursprung in vorgelagerten Lieferketten haben und sich nachgelagert ausbreiten, hat produzierenden Unternehmen in den letzten Jahren Milliarden von Schweizer Franken an potenziellen Einnahmen gekostet. Angesichts der statistischen Grenzen von Risikomanagement-Methoden zur Bewältigung dieser Risiken ist die angebotsseitige Resilienz (Supply-Side Resilience; SSRES) zu einem Thema von strategischer Bedeutung für Unternehmen geworden. Folglich stehen Einkäufer in produzierenden Unternehmen unter dem Druck, die Widerstandsfähigkeit ihrer Lieferkette zu erhöhen, scheitern jedoch oft an der Umsetzung. Eine wesentliche Barriere stellt dabei die Operationalisierung der SSRES, also die Identifikation und Quantifizierung von geeigneten Managementpraktiken dar. Obgleich die wissenschaftliche Literatur zur SSRES zunimmt, bietet die Forschung bisher keinen ganzheitlichen Ansatz zur Durchführung pragmatischer Aufwand-Nutzen-Analysen hinsichtlich der SSRES-Praktiken.

Folglich zielt die vorliegende Forschung darauf ab, eine Methode zur Operationalisierung der SSRES zu entwickeln. Diese beinhaltet (1) die Konzeptualisierung der SSRES, (2) die Messung der Wirksamkeit von SSRES-Praktiken und (3) die Messung der Kosten von SSRES-Praktiken. Die Practice-Based View, die Kontingenztheorie und die «Rational Choice»-Theorie werden als theoretische Linsen für die Untersuchungen verwendet. Die Forschung umfasst eine rein qualitative Studie und zwei Mixed Methods Studien, die sich jeweils einer Komponente zur Operationalisierung widmen. Die erste Studie zur Konzeptualisierung von SSRES stützt sich auf ein komparatives Fallstudiendesign mit sechs Fällen. Die zweite Studie zur Messung der Wirksamkeit von SSRES-Praktiken umfasst eine systematische Literaturrecherche und eine Fallstudie. Die dritte Studie über die Kostenmessung von SSRES-Praktiken stützt sich auf ein allgemeines Fallstudiendesign mit fünf Fällen. In einer Synthese werden die Methoden aus den vorangegangenen Studien zu einem anpassungsfähigen Aufwand-Nutzen-Analyse-Konzept zusammengefasst.

Ausgehend von den Studienergebnissen wird eine ganzheitliche Methode namens RESPIRE vorgestellt, welche unternehmensspezifisch konkrete Managementpraktiken zur Erhöhung der SSRES empfiehlt. Die Methode besteht dabei aus (1) einer Begriffsklärung der SSRES unter Einbezug von Kontingenzvariablen und einem

Katalog relevanter Praktiken zur Erhöhung der SSRES, (2) einem Leitfaden für die Effektivitätsmessung von SSRES-Praktiken mit spezifischen KPIs und (3) einen Leitfaden für die Schätzung der Kosten von SSRES-Praktiken.

Das vorgeschlagene RESPIRE-System helfen den Entscheidungsträgern nicht nur, die SSRES besser zu verstehen, sondern auch, die Effektivität der Praktiken kontinuierlich zu überwachen Damit trägt diese Dissertation dazu bei, den allgemeinen Mangel an empirischer Forschung zu SSRES-Praktiken zu überwinden und den neuen Forschungsstrang des Resilienzmanagements für den Einkauf von produzierenden Unternehmen zu erschliessen.

# 1 Introduction to the research on supply-side resilience operationalization for manufacturing companies

The present research empirically examines the operationalization of supply-side resilience for manufacturing companies (MCs). While Section 1.1 aims to motivate the research from a managerial perspective, Section 1.2 presents the relevance of this topic from a theoretical perspective. Research objectives are derived from the managerial challenges and theoretical shortcomings in Section 1.3. Finally, Section 1.4 outlines the dissertation's structure.

## 1.1 Managerial relevance

Since the 1980s, buyers of MCs have mainly prioritized efficiency over redundancy (Schuster et al., 2021). With buyers seeking low prices during the acquisition of raw materials and product parts, established suppliers have generally experienced a rise in cost pressure and found themselves in competition with those from low-cost countries (Bremen, 2010). Concepts such as "lean" and "just in time" were adopted in MCs to reduce inventory levels and reduce capital commitment (Ward & Zhou, 2006). Technological trends have reduced product lifecycles and added more speed to value creation processes (S. M. Lee et al., 2012). Meanwhile, the share of global procurement from countries with low political stability (50$^{th}$ percentile or less) has increased from 16 percent in 2000 to 29 percent in 2018 (Lund et al., 2020). A study by Lund et al. (2020) indicates that in 2020, roughly 80 percent of global trade was conducted with countries where political stability scores were deteriorating. Also, an increased reliance on digital systems engenders an increased exposure to cyberattacks. According to a recent study, the number of new ransomware alone doubled from 2018 to 2019 (Trustwave, 2019). While today's hyper-connected yet complex and geographically distributed supply chains (SCs) enable the rapid and efficient provision and diffusion of material, information, and cash, they increase the number of weak points vulnerable to external perturbation (Azadegan & Dooley, 2021). To deal with the recurring risks that naturally emerge with this complexity and acceleration, MCs adopted a series of SC risk management (SCRM) strategies and practices (Sutherland et al., 2016). Most implemented SCRM approaches rely on risk identification and containment, assuming that all risks are predictable to a certain extent (Pettit et al., 2013). This predictability is based on statistical assumptions inferred from historical data, which quickly reaches its limits for extremely rare or one-time risks with high economic consequences.

During the past decade, geopolitical, environmental, and economic turbulence have increased both the frequency and magnitude of unexpected supply disruptions (Lund et al., 2020; Rajesh & Ravi, 2015). Events such as the Japanese earthquake in 2009 (Pettit et al., 2013), the outbreak of SARS-CoV-2 in 2020/21 (Gray & Wynstra, 2020; Ivanov & Dolgui, 2021b), and the Russian-Ukrainian war in 2022 (Jagtap et al., 2022) were unexpected for many MCs and have revealed the weaknesses in their SCRM strategies and practices. Depending on the nature and length of the disturbance tied to these events, the associated consequences can be devastating for a company or a SC, leading to widespread production halts and high revenue losses caused by supply shortages (Hosseini et al., 2019; Ivanov et al., 2017; Simchi-Levi et al., 2014). For companies in most sectors, a single prolonged shock to production could wipe out 30 to 50 percent of one year's EBITDA (Lund et al., 2020). Most recently, a large-scale German survey revealed that around 90 percent of MCs in the automotive, mechanical, and electrical industry have experienced some form of material shortage and challenges during the procurement of pre-products and raw material in March 2022 (ifo Institut, 2022).

Even though these unexpected risks may arise from anywhere, they occur primarily in the upstream SC and escalate downstream (Manuj & Mentzer, 2008; Nitsche & Durach, 2018), making a MC's interface with its upstream SC (i.e., the buyer) decisive in managing the subsequent disturbances. With SCRM models unable to cover this new type of supply-side threats, however, buyers are searching for new concepts that address shortcomings and aid them in making the right resource allocation at the right time and cost to mitigate disruption damage and recover quickly (Dabhilkar et al., 2016). Against this backdrop, SC resilience has become a topic of strategic importance for many MCs as they attempt to resist to and to recover from the impact of unexpected disruptions that cannot be avoided (Melnyk et al., 2014, 2021; Schuster et al., 2021).

While the term resilience is often discussed in a biological and psychological context, SC resilience intends to address those SC risks preceding unexpected disruptions that SCRM is not effective in capturing (Pettit et al., 2010). Resilience can therefore be seen as a complementary concept to SCRM. Notwithstanding its breadth of definitions and perceived importance, SC resilience largely remains an abstract concept for buyers, who often do not understand what it means for their purchasing practices (Hosseini et al., 2019; Scholten & Schilder, 2015). Currently, there are several reasons for this lack of understanding.

Firstly, buyers often do not know which parts of existing SC resilience concepts are relevant for their buying organization from an upstream SC-facing actor's perspective, i.e., which parts address supply-side threats. The concept of supply-side resilience (SSRES) has been introduced in literature (Dabhilkar et al., 2016; Pereira et al., 2020), but lacks empirical research. In general, many concepts exist to grasp general SC resilience, yet they lack practicality; supply-side concepts still lack palpability. In addition, buyers have no way to figure out how effective a SSRES practice is for their organization. While they implicitly adopt SSRES practices, the adoption can be characterized by impromptu, situation-dependent decision-making instead of systematic and structured assessments in line with a resilience strategy (Melnyk et al., 2021). This decision-making nature leaves buyers struggling to explicitly identify the most and least effective practices for their buying organization. Finally, buyers have difficulties tracking expenditures in SSRES practices, mainly due to a lack of documentation, data aggregation, and data availability across the scope of different practices (Aldrighetti, Battini, Ivanov, et al., 2021).

In summary, there is a current dearth of practitioner knowledge on how to operationalize SSRES, i.e., to make it measurable in terms of both effectiveness and cost. Practitioners lack ways to judge whether a decision to adopt, maintain, and use a SSRES practice ties into an economically feasible strategy.

A series of managerial challenges can be identified:

- *Managerial challenge 1 (M1) – Identification of SSRES practices*: Buyers of MCs accept that resilience is strategically important, but they are overwhelmed with characterizing resilience for their buying organization. They, therefore, need a better understanding of what kind of practices exist that have the potential to bolster their SSRES. They require an overview of SSRES practices and ways in which they can be adopted.
- *Managerial challenge 2 (M2) – Evaluating the effectiveness of SSRES practices*: MC buyers do not know which resilience practices are most and least effective for mitigating disruption damage or recovering from a disruption. They need a

way to figure out how to determine the effectiveness of SSRES practices for their organization in order to make informed adoption decisions.

- *Managerial challenge 3 (M3) – Assessing the cost of SSRES practices*: MC buyers have no systematic way of determining how much resilience practices cost in terms of setup, maintenance, and usage. A method that guides even those practitioners with a lack of process cost data is required to evaluate expenditures.

Hence, the dissertation's *unit of analysis* entails *SSRES practices* for the buying organization of MCs.

## 1.2 Theoretical relevance

The examination of SSRES operationalization by MCs can be considered cross-sectional, as it draws on different research streams. Although it is primarily based in SCRM[1], it also touches upon general and manufacturing-related insights from purchasing and supply management (PSM) and strategic cost management (see Sections 2.1 and 2.4).

Research on SC resilience has been conducted for around two decades (Pereira et al., 2014), and academic interest is becoming increasingly relevant in light of more frequent and more impactful SC disruptions (Fiksel et al., 2014; Ivanov, 2021a; Kochan & Nowicki, 2018; Pettit et al., 2010; Wieland & Wallenburg, 2013). Initial efforts by scholars included the investigation of organizational resilience to address unexpected disruptions within its SC through the development and interrelation of higher-order constructs. For instance, Pettit et al. (2010; 2013) juxtaposed a company's capabilities and vulnerabilities in an area of tension in the quest for "optimal resilience". Other authors have introduced strategies, enablers, and elements to make up a holistic resilience concept (A. Ali et al., 2017; I. Ali et al., 2017).

For further structuring, authors have suggested the temporal subdivision into proactive and reactive resilience (Dabhilkar et al., 2016; J. Wang et al., 2018). While proactive resilience focuses on capabilities and strategies before a disruption occurs, reactive resilience addresses post-disruption capabilities and strategies (A. Ali et al., 2017). With the increase in SC disruptions that last longer and can put the survival of an organization

[1] A clear distinction between SCRM as a *concept* with an associated body of methods and constructs and SCRM as a *research stream* is made.

at risk, concurrent resilience was introduced. Concurrent resilience addresses capabilities and strategies that are essential during a disruption.

In general, authors have demonstrated that resilience has a positive effect on long-term organizational performance, leading to a competitive advantage (Fiksel, 2015; Melnyk et al., 2014; Wieland & Wallenburg, 2013). Recognizing that not only organizations but whole SCs compete (Lambert et al., 1998), more research on inter-organizational resilience, i.e., network resilience, emerged during the 2010s (Rezapour et al., 2017; Tukamuhabwa et al., 2015; J. Wang et al., 2016). Due to the reality of low transparency and little collaboration efforts across SCs (Blecker & Kersten, 2006; Scholten & Schilder, 2015), the practicality of network resilience was deemed highly limited. This revealed a misbalance between comprehensiveness and practicality for the research area.

The introduction of resilience to upstream SC segments or dyads to address supply-side threats has been selectively investigated, but this transfer is still in its infancy. Some recent studies link the role of procurement and SC resilience capabilities (Dabhilkar et al., 2016; Pereira et al., 2014). This has led to the birth of a procurement-specific resilience concept: supply-side resilience (SSRES) (Pereira et al., 2020). These studies have mainly characterized SSRES as a bundle of dynamic capabilities, yet they stay on a strategic level due to the use of higher-order constructs and consequently fail to apply on an operational level. Considering the thorough conceptualization of general SC resilience and the immaturity of its supply-side version, high potential exists to further reinforce the transfer to PSM.

Lower-order operational constructs, such as practices and activities, are selectively investigated but suffer from lack of theoretical rigor and alignment. On one hand, qualitative literature identifies practices and activities such as “supply chain network design,” “velocity and acceleration,” and “sensing and interpreting,” leaving plenty of room for interpretation (Fiksel et al., 2014; Pettit et al., 2010, 2013). On the other hand, quantitative studies construct complex analytical models to examine the specific performance effects of individual practices, such as inventory decentralization or backup suppliers (Hosseini et al., 2019; Pires Ribeiro & Barbosa-Povoa, 2018). Most of these studies track change in KPIs, such as order lead time and supplier rejection rate, with specific practices, thus measuring the effectiveness of the practice during or after disruptions (Aldrighetti, Battini, & Ivanov, 2021; Cavalcante et al., 2019; Kinra et al., 2020). These measurements are mostly completed via simulation of disruptions, providing little foundation for empirical research. This creates an area of tension between the high abstraction of qualitative research on SSRES practices and the lack of theoretical rigor coupled with high complexity in quantitative studies. The result is that SSRES are prevented from being operationalized in an integrative and theoretically sound manner.

Aside from effectiveness measurement, the economic feasibility of SSRES practices cannot be interpreted without assessing associated costs (Hof & Rideout, 1989). Several studies identify different types of costs and heuristics to express efforts to build organizational or network resilience. These can be generally partitioned into proactive investment costs and evaded damage costs (Aldrighetti, Battini, Ivanov, et al., 2021). Similar to effectiveness measurement literature, resilience cost studies use simulated data and complex cost functions, which makes the transferability of their implications to different company and environmental contexts challenging (Barroso et al., 2015; Carvalho, Azevedo, et al., 2012; Carvalho, Barroso, et al., 2012; Carvalho et al., 2011). There is currently no method that measures the cost of a variety of practices for a buying organization.

Tying the two dimensions of cost and effectiveness together, holistic methods to measure the economic feasibility of resilience by juxtaposing the two remains a void in research. As the application of cost-effectiveness analyses (CEAs) on a broad portfolio of practices could potentially improve a buyer's resource allocation in building resilience, a better understanding of the associated problems and necessary method is urgently needed to push the knowledge frontier on SSRES operationalization by MCs further.

According to the literature analysis on supply-side resilience operationalization by MCs, the managerial challenges presented in Section 1.1 have remained mostly unaddressed. Hence, it is necessary address the following theoretical shortcomings:

- *Theoretical shortcoming 1 (TS1) – Lacking transfer of SC resilience to the procurement setting*: The transfer of findings from SC resilience research to the procurement setting has not yet been completed. Resilience from the perspective of procurement has been punctually investigated in terms of dynamic capabilities, however these studies generally lack theoretical rigor.
- *Theoretical shortcoming 2 (TS2) – Abstract formulation of SSRES practices*: While higher-order constructs have been well investigated in resilience research,

the bridge between higher-order resilience constructs and their relationship to lower-order constructs such as practices and activities is still fragmented. Current research on the latter lacks alignment and clarity, creating a barrier toward operationalization of the concept.

- *Theoretical shortcoming 3 (TS3) – No holistic cost-effectiveness measurement method for operationalizing SSRES*. Efforts to operationalize SSRES to measure economic feasibility includes either abstract, strategical insights or specific, complex operations research models, revealing a clear and addressable research gap. Currently, there is no systematic way to allocate cost elements and drivers to a portfolio of SSRES practices.

## 1.3 Research objectives

With the managerial (see Section 1.1) and theoretical (see Section 1.2) relevance of this research, the overarching research objective ($RO_0$) is derived:

> $RO_0$: An examination of how to operationalize SSRES in terms of cost and effectiveness for MCs under certain circumstances.

Three partial research objectives ($RO_1$–$RO_3$) that build on each other are pursued to approach $RO_0$. This approach enables the addressing specific shortcomings of existing research on SSRES operationalization and allows for contribution to the young field of SSRES.

While buyers of MCs recognize that addressing unexpected supply-side risks through resilience is becoming more and more essential for their survival in the light of turbulent environments, many have difficulties grasping resilience. Literature on resilience includes many explanations and definitions (A. Ali et al., 2017), and the relevance of many resilience constructs, such as phases, strategies, and capabilities, are not clear. Furthermore, the systematization of constructs from a strategical to an operational level is highly fragmented. A holistic concept that acts as a foundation for procurement-specific resilience operationalization largely remains unaddressed. Hence, the first partial research objective is formulated as follows:

> $RO_1$: A conceptualization of SSRES for MCs that includes practices and their connection to higher-order constructs.

Research sufficiently defines different KPIs to measure SSRES for a variety of different practices (Barroso et al., 2015; Carvalho & Machado, 2007; Zavala et al., 2018). However, explanatory models are often complex, based on simulated disruptions, and not applicable to a set of practices. Additionally, real-world data is not frequently used due to lack of availability. From a theoretical perspective, this poses barriers to the operationalization efforts to determine which practices are most and least effective in a certain context. From a managerial standpoint, this prevents practitioners from being able to select which practices they should consider adopting in their situation. The second partial research objective can therefore be formulated as follows:

> *$RO_2$*: An examination of methods to measure the effectiveness of SSRES practices for MCs.

Research must fully explore how to model the cost of resilience in terms of expected damage cost or the investment cost through adopted practices. Even though pressure to increase the resilience of buying organizations exists, managers currently have no way to systematically track expenditure of resilience practices in a broad manner. As it is of great importance to understand the cost drivers of resilience practices for improved resilience management, the third partial research objective can be stated as follows:

> *$RO_3$*: An examination of methods to measure the cost for a wide variety of SSRES practices for MCs.

Figure 1 provides a comprehensive outline of the managerial and theoretical relevance culminating in the dissertation's research objectives.

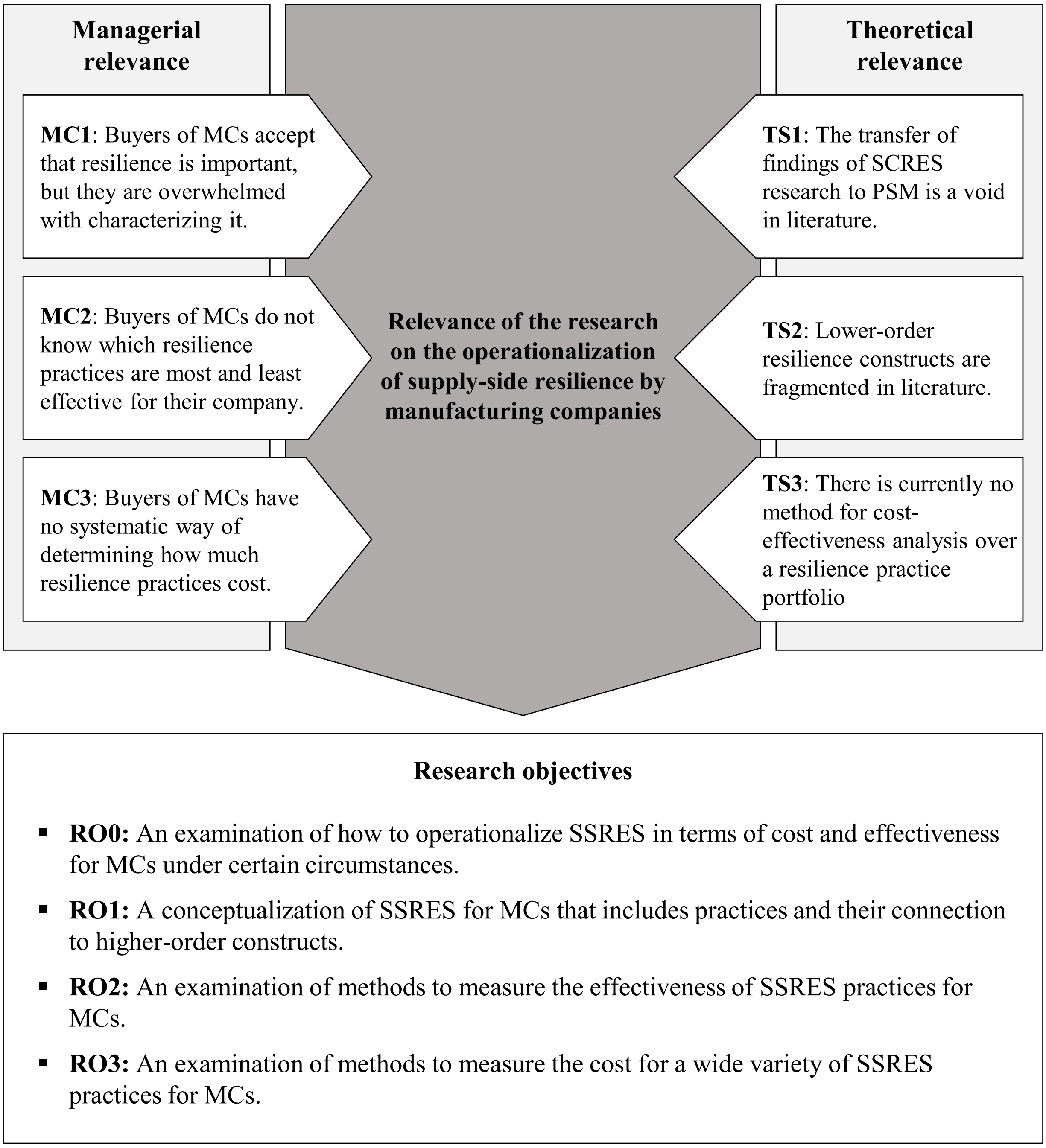


**Figure 1.** Managerial and theoretical relevance and the resulting research objectives on SSRES operationalization for MCs

## 1.4 Thesis structure

The dissertation is structured into six chapters (see Figure 2).

*Chapter 2* provides the conceptual background of the dissertation. It outlines characteristics of the procurement of MCs (Section 2.1). After that, an overview of supply-side threats with a particular focus on related terminology is presented (Section 2.2) to help characterize associated management concepts that address these threats, including supply-side resilience (Section 2.3). Section 2.4 discusses the relevance of SSRES operationalization in the context of procurement in MCs.

*Chapter 3* entails a review of the literature on SSRES operationalization. Starting with an overview of studies on SSRES conceptualization (Section 3.1), the chapter continues with a literature review of SSRES measurement and effectiveness evaluation of associated practices (Section 3.2) and the cost evaluation of SSRES practices (Section 3.3). Both general and procurement-specific research is analyzed. The chapter concludes with derived research gaps and questions (Section 3.4).

*Chapter 4* explores the theoretical underpinnings of the dissertation. Section 4.1 presents the general research approach and philosophy. Section 4.2 describes the theory selection procedure, including the identification of theories that are relevant to the research context. The subsequent Sections 4.3 to 4.5 manifest the selected theories' contributions to the dissertation. This chapter concludes with the theoretical framework, which illustrates the application of the theories within the scope (Section 4.6).

*Chapter 5* provides an overview of the studies conducted within the dissertation project (Section 5.1). Sections 5.2 to 5.4 briefly summarizes the objectives, methodologies, key findings, and contributions of the studies included in this research. Section 5.5 presents the resulting method of the dissertation to operationalize SSRES for MCs.

*Chapter 6* entails the contributions of the studies with a focus on the implications for the overarching research objective (Section 6.1). Afterwards, managerial implications for the individual studies and the resulting method are presented (Section 6.2). The chapter is concluded with a discussion of the limitations and suggestions for future research (Section 6.3).

The Appendix contains the full texts of the three studies conducted for this dissertation.

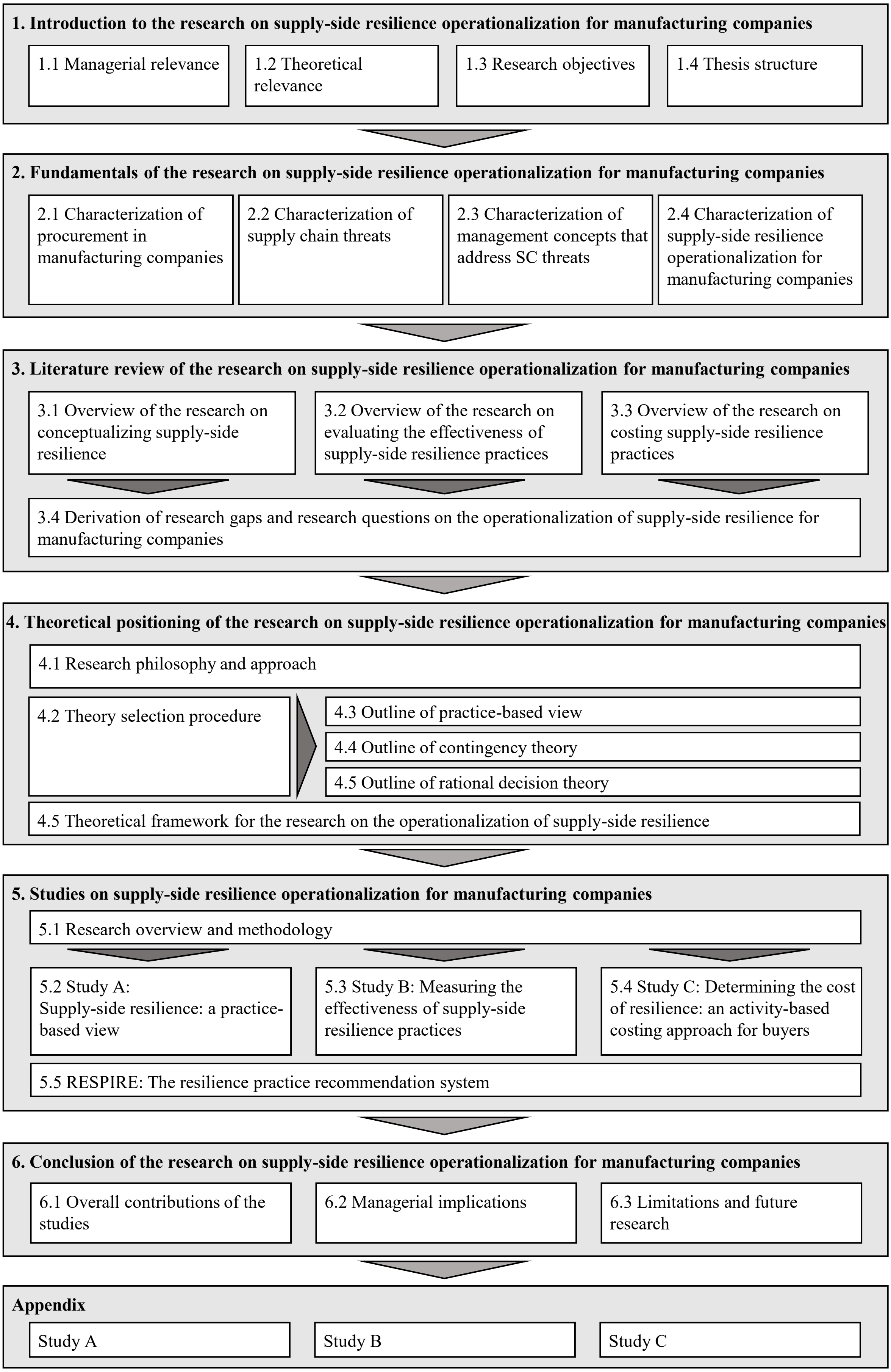


**Figure 2.** Structure of the dissertation

# 2 Fundamentals on the research on supply-side resilience operationalization for manufacturing companies

In this section, the conceptual groundwork for the research on SSRES operationalization for MCs is provided. First, the procurement function in MCs is characterized with a particular focus on global sourcing (Section 2.1). In this context, the challenges of global sourcing are illuminated through a conceptual overview of supply-side threats (Section 2.2). Next, management concepts to address these supply-side threats are introduced, including SSRES (Section 2.3). Finally, the relevance of the operationalization of SSRES for MCs is outlined (Section 2.4).

## 2.1 Characterization of procurement in manufacturing companies

A manufacturing company's (MC) procurement is one of the main functions of its internal value chain, ensuring the external supply of the company with the input required for value creation (see Figure 3). This input usually includes material goods, services, energy products, and rights – also known as procurement objects –which are sourced from procurement markets. Typically, labor markets, as well as money and capital markets, are excluded from the responsibility sphere of the procurement function (Bräkling & Oidtmann, 2019; Bremen, 2010).

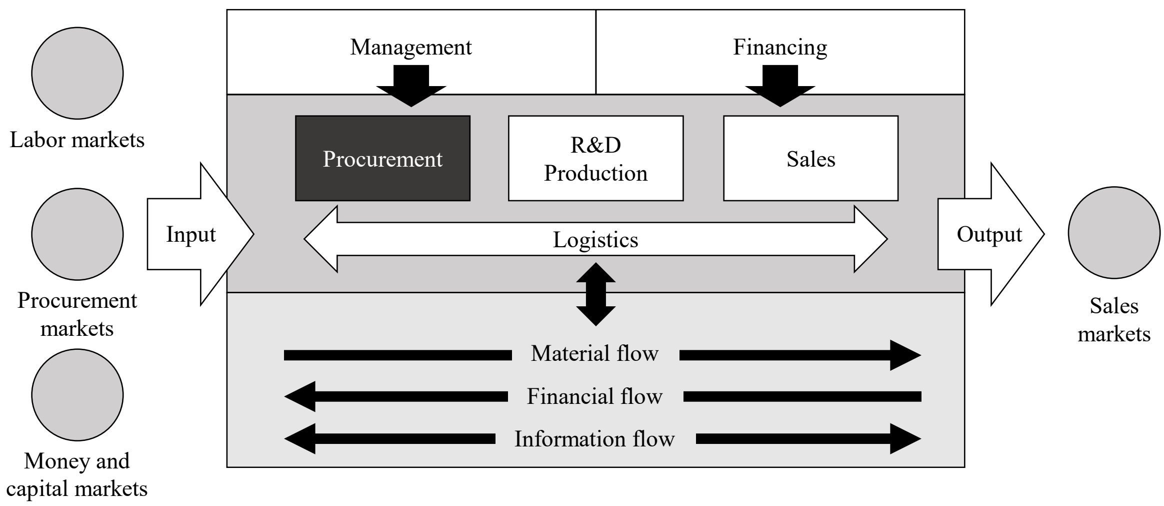


**Figure 3.** The role of procurement in the value creation of an MC (adapted from Bräkling & Oidtmann, 2019 and Essig et al., 2013)

In general, procurement covers all company- and market-related activities from initiation to finalization, when any necessary objects that are not self-produced are made available to a company (Arnold, 2008). While the company-internal functions are intertwined, the procurement function is distinct from R&D and production, sales, and logistics. The procurement acts as an "internal service provider" for both logistics and R&D/production (Bräkling & Oidtmann, 2019). For example, transaction and transfer activities are coordinated with logistics, and procurement object requirement tasks are coordinated with R&D/production.

The tasks of procurement in MCs can be divided into a demand-neutral strategic part and a demand-related operational part (Bremen, 2010). Strategic procurement entails the definition of the procurement strategy, supply planning, make-or-buy decisions[2], supply market research, supplier selection, and contract definition.[3] Operational procurement entails the calculation, completion, and monitoring of purchase orders, as well as the receipt of goods, transport, storage, and billing (P. F. Johnson et al., 2011).

The term "purchasing" is used in literature mainly for the operational activities of procurement and can be considered a subset of the latter. Furthermore, the term "sourcing" is associated with a strong willingness by business partners to cooperate and integrate (Trent & Monczka, 2003). Following the Supply Chain Operations Reference (SCOR) model, "source" is used synonymously with the term "procurement" in the context of this dissertation[4] (see SCOR, 2017). Finally, the term "buying" is mostly used in the context of trade companies (Borghini et al., 2006), however, due to its common usage, we will refer to individuals overseeing procurement and managing its resources as "buyers".

According to Pereira et al. (2014, p. 628), procurement has evolved from a "simple business function accountable for planning, implementing, evaluating and controlling purchase decisions" to a vital resource management function (Ellram & Carr, 1994; Lysons & Farrington, 2010; Monczka et al., 1998). Amongst other factors, a driver of this change was the demonstration by Kraljic (1983) of potential to reduce costs through

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[2] Make-or-buy decisions can be viewed as decisions about whether to insource or to outsource. "Insourcing refers to reversing a previous buy decision. An organization chooses to bring in-house an activity, product, or service previously purchased outside. Outsourcing reverses a previous make decision. Thus an activity, product, or service previously done in-house will next be purchased" (P. F. Johnson et al., 2011, p. 121)

[3] According to Carr & Smeltzer (1997), strategic procurement is "the process of planning, implementing, evaluating, and controlling strategic and operating purchasing decisions for directing all activities of the purchasing function toward opportunities consistent with the firm's capabilities to achieve its long-term goals." (Carr & Smeltzer, 1997, p. 201).

[4] According to the SCOR model (2017), sourcing describes "the activities associated with ordering, delivery, receipt and transfer of raw material items, subassemblies, products or services".

better integration and a holistic approach. Today, the significance of procurement as a strategic business function is well understood (González-Benito, 2007; Krause et al., 2001), and it is seen as the "new" source of competitive advantages (Essig et al., 2013), which are engendered in its "strategic component" (Arnolds et al., 2013) by managing entire supply networks (Grochla & Schönbohm, 1980).

Such a network is composed of a multiplicity of actors and is represented in its most straightforward form as a linear chain or sequence (Essig et al., 2013). It is common to have a multi-level value network, with the company's direct suppliers forming the first level (tier 1), their respective sub-suppliers forming the second level (tier 2), and so on (Bremen, 2010). Beyond the direct supplier network, a complex network of upstream (supply-side) and downstream (demand-side) actors may form. Today, such a network is summarized under the generalized term "supply chain" (SC) (Schönsleben, 2016).

Depending on both the company's internal objectives and the SC's external requirements and constraints, different procurement strategies may be employed (Trent & Monczka, 2003). Among other factors, procurement strategies may depend on the bundling of value creation steps within the procurement object (*modular* and *system sourcing*), the number of suppliers for a specific procurement object (*multiple*, *dual*, *single*, and *sole sourcing*), and the geographic location of the supplier (*global* and *local sourcing*) (Bremen, 2010; Schönsleben, 2007, 2016).

New market opportunities, increased competitiveness, and resulting cost pressures have driven the global expansion of SCs and driven procurement strategies (Kamalahmadi & Mellat-Parast, 2015; Kamalahmadi & Parast, 2017). MCs are striving to offer high levels of customization and expand their product portfolios to meet the challenges of a business environment that is ever-changing due to technological advances (Sreedevi & Saranga, 2017; Wagner & Bode, 2008). Having gained attention in both literature and practice since the late 1980s, global sourcing aims to use the best possible source of supply by extending the geographical radius of procurement (Trent & Monczka, 2003). Its advantages are mainly cost savings, increased delivery capability and flexibility, and access to higher-value products and technologies that are not available locally (Bogaschewsky et al., 2017; Schönsleben, 2016; Stanczyk et al., 2017).

While global sourcing for MCs has led to decreased cost for products and increased access to innovation (Yu & Lee, 2019), it naturally poses systemic threats to global SCs due to the latter's length and complexity (Dubey et al., 2019; Fiksel, 2015; Pettit et al., 2010). For example, these risks manifested themselves in SC disruptions caused by supplier insolvencies during the 2007/2008 subprime crisis, sustainably changing the landscape of global trade. While trade activity sharply decreased and made a quick recovery afterward, the pre-disruption growth rate was cut in half (7.6% between 2000 and 2008 versus 3.5% between 2009 and 2018), indicative of subsequent large-scale de-risking (James & Steger, 2021). Drivers adding to this countertrend include shorter delivery times, higher company-internal process automation, and environmental awareness (Livesey, 2017). In summary, decision-makers are continuously faced with balancing operational efficiency with exposure to supply-side threats that result in SC disruptions.

## 2.2 Characterization of supply-side threats

This section is dedicated to understanding the characterization and emergence of supply-side disruptions through four different types of supply-side threats: uncertainty, risk, disturbance, and disruption (Ivanov & Sokolov, 2010). Figure 4 illustrates the four threats and their interrelation, as well as their respective relation to supply-side performance.

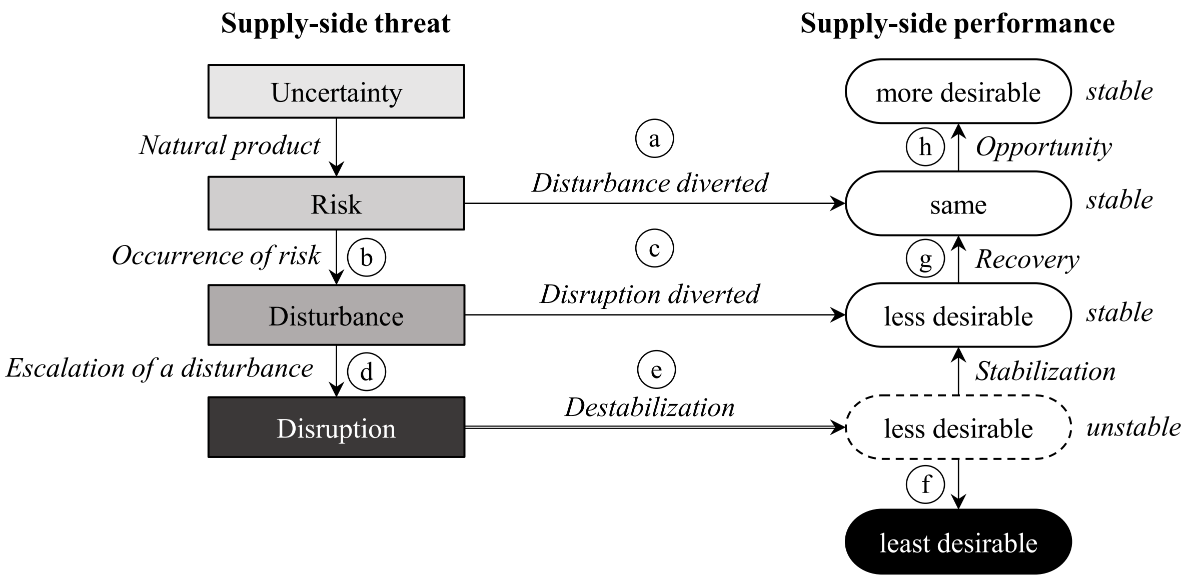


**Figure 4**. The four supply-side threats in relation: uncertainty, risk, disturbance, and disruption (adapted from Ivanov & Sokolov, 2010)

*Uncertainty* describes an integral SC property "characterizing the incompleteness of knowledge about the system and the conditions of its development" (Ivanov & Sokolov, 2010). Being a highly perspective-dependent property, uncertainty exists in any system with general complexity. While uncertainty may be unavoidable in modern SCs, its outcomes vary. On one hand, uncertainty can lead to positive deviations from an expected result and business opportunities (Ivanov & Sokolov, 2010). On the other hand, uncertainty can lead to negative, unexpected deviations whose extent and consequences can fall outside experience (Melnyk et al., 2014). Exemplary uncertainty aspects relevant for buyers include outsourcing and environmental uncertainty affecting the upstream SC (Thun & Hoenig, 2011).

*Risks* occur naturally due to uncertainty in a system: One of the earliest definitions describes risk as “measurable uncertainty” (F. H. Knight, 1921).[5] Risks are composed of three elements: the event of occurrence (disturbance), the probability or likelihood of the event occurring, and the impact or consequence of the event if it occurs (Norrman & Jansson, 2004). While risks have been systematically studied since World War II, SC risks did not emerge in literature until the 1980s (Kleindorfer & Saad, 2005). Many different types of risk categorization exist based on multiple perspectives, such as internal, external, financial, and operational (Aldrighetti, Battini, Ivanov, et al., 2021; Y. Fan & Stevenson, 2018; Ho et al., 2015). Furthermore, Christopher and Peck (2004) identify four main categories of risk: manufacturing/process, control, supply-side, and demand-side. Supply-side risks relate to “the processes, controls, assets and infrastructure dependencies of the organizations [upstream] and adjacent to the focal firm” (Christopher & Peck, 2004, p. 5). One example of supply-side risk resulting from both outsourcing and climate change uncertainty is the risk of a natural catastrophe in the region of a critical supplier.

One of the most common ways to identify and evaluate risks is through a probability-impact assessment matrix (see Figure 5). Depending on the allocation of the risk within the matrix, three types of risks can be defined: First, *negligible risks* entail all risks in the low-probability, low-impact (LP/LI) quadrant. Due to their inherent nature and low business impact, these risks enjoy little to no attention (Kumar Sharma & Sharma, 2016). Second, *operational risks* cover all risks that fall into the high-probability sphere. These can be either low-impact (LI/HP) or high-impact (HI/HP). In general, operational risks can be identified, analyzed, controlled, and regulated (Götze & Blöch, 2002;

[5] Risks are often equated with “vulnerabilities”, which means “at risk” (Blecker & Kersten, 2006).

Hallikas et al., 2004; Ivanov & Sokolov, 2010; Khan & Burnes, 2007; Pfohl, 2008; Rao & Goldsby, 2009). These types of risk provide a high degree of empiricism due to their frequent occurrence. Finally, *disruptive risks* describe those risks occurring with high impact and low probability (HI/LP). Disruptive risks are most difficult to identify, measure, and control, but have a potentially catastrophic impact. From a statistical point of view, these risks have outlier status, and no methods can explain their diverse impact nor calculate their likelihood (Taleb, 2007). Decision-makers will face challenges in trying to estimate the potential impact of disruptive risks, and thus will not be able to derive appropriate mitigation measures.

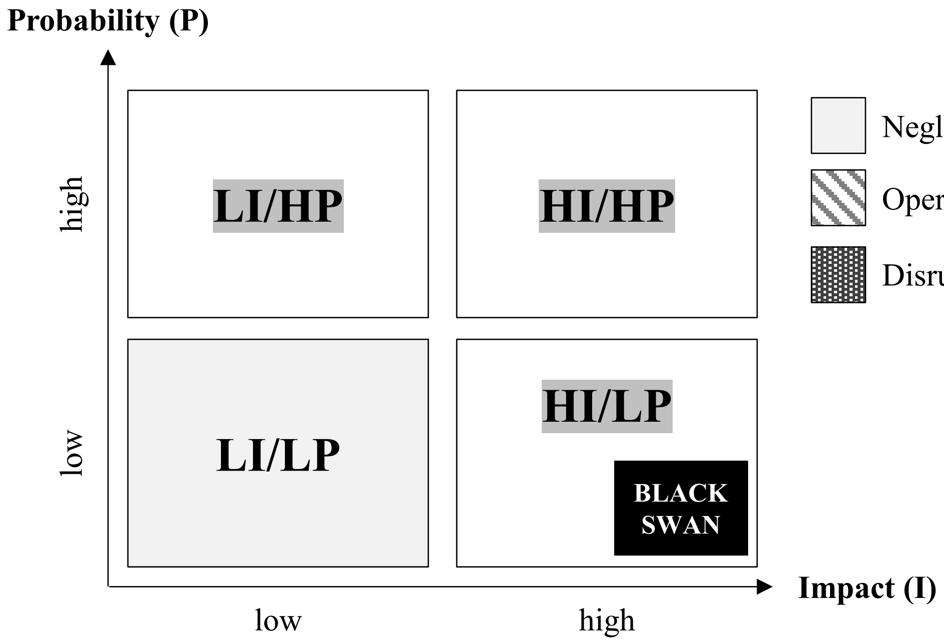


**Figure 5.** An exemplary probability-impact risk assessment matrix

As an extreme subset of HI/LP risks, Taleb (2007) introduced the "black swan" concept. Decision-makers will neglect the relevance of black swan events and assign zero probability, removing them from probability distributions often used in risk management (Aggarwal & Bohinc, 2012; Heckmann et al., 2015; Taleb, 2007). Black swan events are characterized by high direct and long-lasting indirect impact (Aggarwal & Bohinc, 2012; Taleb, 2007) and can be defined as "large-scale unpredictable and irregular events of massive consequence" (Taleb, 2012, p. 20). Though super events (which will be discussed shortly) occur every five to ten years, black swan events are considered 100-year events (Aggarwal & Bohinc, 2012), with examples being the terrorist attacks of 9/11 (Nafday, 2011) or the Japanese tsunami (Pettit et al., 2013). Since academics expect the likelihood of pandemics to rise to more than once a century, some scientists do not consider SARS-CoV-2 a black swan event (Sodhi & Tang, 2021), while others do (Antipova, 2021; Brugarolas et al., 2020). Only in the aftermath of such events can their occurrence be explained, making them easier to predict in the future (Aven, 2013; Taleb, 2007).

*Disturbances*[6] are the occurrence of risks (see *Step b* in Figure 4). A disturbance may cause a less desirable yet stable performance level (see *Step c* in Figure 4), which can be recovered to the original state. In cases where disturbances can be avoided, the supply-side segment, dyad, or focal company returns to their original performance (see *Step a* in Figure 4). A disturbance is tied to an "event" (Macdonald & Corsi, 2013). Depending on the measures and practices in place, these disturbances can either be diverted, or these can escalate into disruptions. An exemplary disturbance tied to the risk of natural catastrophe occurring could be the triggering of a tsunami. At that point in time, the supplier has not been affected directly, but a supply-side disruption is imminent if appropriate preparatory measures have not been taken by the company.

*Disruptions* are the escalating result of disturbances. They intensely affect operations, processes, plans, goals, or strategies (Ivanov & Sokolov, 2010). Supply-side disruptions disrupt the normal flow of goods and materials within a SC, resulting from constraints on the supply market and new technologies or product designs (Craighead et al., 2007; Hendricks & Singhal, 2003; Kleindorfer & Saad, 2005; Wagner & Bode, 2008; Zsidisin et al., 2000). Supply-side disruptions occur in the upstream SC. Ivanov (2021) distinguishes an *instantaneous disruption* (i.e., an event with immediate impact such as an earthquake or an explosion) from a *super disruption* (Ivanov, 2021a, 2021b). A super disruption, synonymous with a SC crisis, is a "long-term disrupted state that is characterized by an unstable current situation and uncertainty about future developments in the markets, supply base, and capacities, which together entail a danger of SC collapses and interruption of the market provision of goods and services" (Ivanov, 2021, p. 5). Akkermans and van Wassenhove (2018) call this phenomenon a "supply chain tsunami", which—like their ecological counterparts—can "fundamentally alter the morphology of the business or even the industry it hits, with structural effects on the supply chain

[6] According to Ivanov & Sokolov (2010), disturbances can also be described as perturbation influences.

observable many years after the original event" (Akkermans & van Wassenhove, 2018, p. 65). A distinction between the terms is made in Table 1.

**Table 1.** Instantaneous disruptions vs. super disruptions (adapted from Ivanov et al., 2021b and Akkermans and van Wassenhove, 2018)

| | Instantaneous disruption | Super disruption |
|---|---|---|
| **Synonyms** | | SC crisis, SC tsunami |
| **Example disturbances** | An earthquake, an explosion | A pandemic, a war |
| **Probability of preceding risk** | low to very low | very low |
| **Impact** | Instant after disturbance | Gradual causing structural changes |
| **Timing** | Single disturbance | Cascades of disturbances |
| **Scope** | Single upstream SC tier | Simultaneous disruptions in supply, demand, and production |
| **Recovery** | Begins after the disruption | Begins during the disruption |

In contrast to instantaneous disruptions, which are characterized by short duration and high intensity, a super disruption's duration is characterized by both gradual degradation and recovery (Ivanov, 2020, 2021b; Paul & Chowdhury, 2021). In super disruptions, SCs have more time to adapt, and the dynamics are more predictable (Nagurney, 2021). Furthermore, instantaneous disruptions are mainly the result of single disturbance, such as natural disasters. While super disruptions may begin with a trigger disturbance with an immediate impact as well, they entail a "disruption tail" with a cascade of subsequent disturbances (Ivanov, 2021b). The scope of instantaneous disruption impact usually remains within a single SC tier and expresses itself as a supply-side, production, or demand-side disruption (Pettit et al., 2013). Production disruptions occur within the MC during the creation of products or services (Pettit et al., 2013). Finally, demand-side disruptions occur in the downstream SC, such as consequences of a demand shock in the sales or distribution channels (Wagner & Bode, 2008). Meanwhile, super disruptions are often a simultaneous mix of all three types (Ivanov, 2021b). In this context, multiple SC tiers are impacted at different times, due to sequential disturbances with no definite end in sight (e.g., lockdowns in different countries at different times; Queiroz & Fosso Wamba, 2021). The final distinction is made for the phase of recovery between an instantaneous and a super disruption. While the recovery for the former occurs instantly after the disruption (e.g., the recovery after an earthquake), the recovery for the latter occurs during the disruption, due to its longevity. This makes the recovery phase after a disruption subject to high levels of uncertainty (Ivanov, 2021b)[7]. Notwithstanding their differences, both types of disruptions have similarities. In both cases, the occurrence probability of the preceding risks is ranked as low or extremely low (Akkermans & van Wassenhove, 2018; Ho et al., 2015). However, some scholars describe their probability as continuously rising, due to macrotrends such as climate change (Kovács & Falagara Sigala, 2021; Sodhi & Tang, 2021). In terms of impact, local, instantaneous disruptions have the potential to turn into globally distributed super disruptions, depending on the circumstances (Azadegan & Dooley, 2021). As an example, the supply-side disruption occurs as soon as the tsunami has hit the supplier, making it unable to deliver and thereby disrupting the previously planned flow of materials.

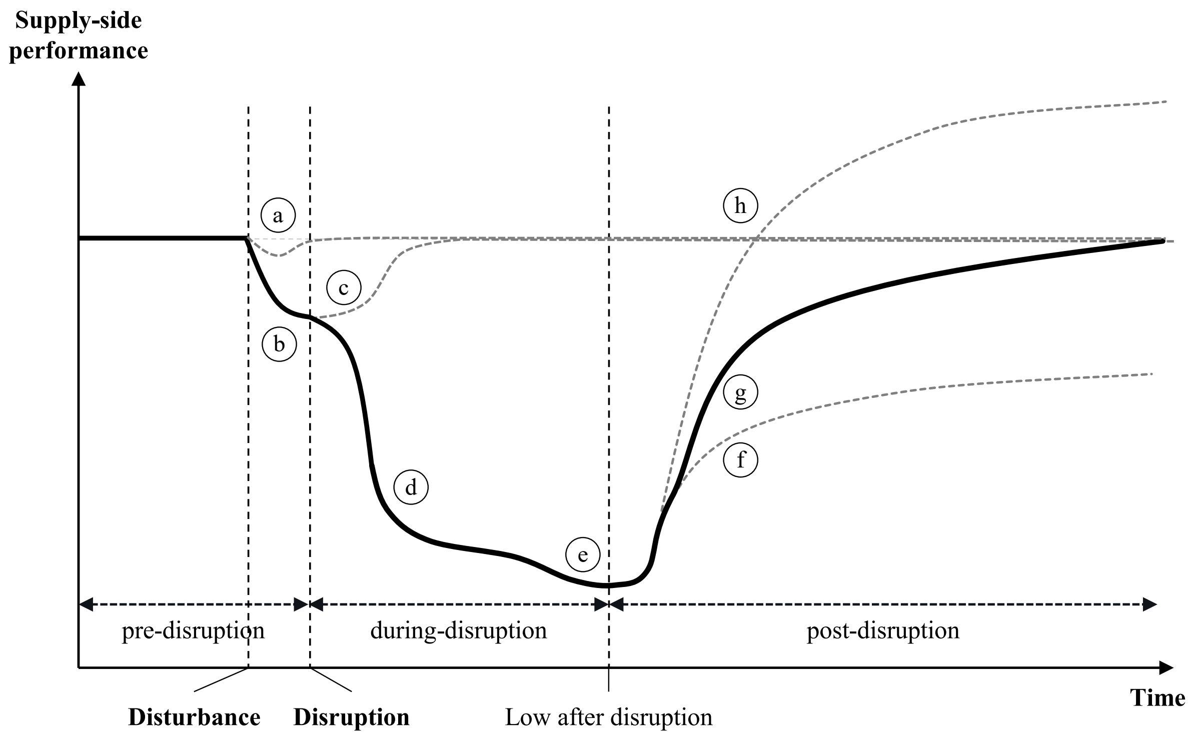


**Figure 6.** The ideal-typical impact of a disruption on supply-side performance (adapted from Sheffi, 2005)

In the pre-disruption phase, potential disruptions can be anticipated, and a response can be prepared (Golgeci & Ponomarov, 2013; Klibi, Martel, et al., 2010; Ponomarov & Holcomb, 2009; Priya Datta et al., 2007). The power of anticipation is highly dependent on the type of disruption (see Section 2.2). At some point in time a disturbance occurs.

[7] A detailed distinction between pre-disruption, during-disruption, and at-disruption phases is made in Section 2.3.

Depending on the measures in place to contain the effects of the disturbance, the performance level stays at the original level (*Step a*) or the performance suffers a deviation (*Step b*). From here, two paths can be taken: Either the supply-side performance is fully restored after the deviation (*Step c*) or a during-disruption phase begins when the escalation enters a path of no return (*Step d*). After the full disruption, the impact severity reaches its maximum (*Step e*), until the post-disruption phase begins. The consequences of SC disruptions include financial losses and reputational damage, which cause demand and security loss (Jüttner et al., 2003; Thun & Hoenig, 2011). While general statements about financial losses during disruptions are unreasonable (Thun & Hoenig, 2011), some examples show that daily losses can amount from USD 50 to USD 100 million (Rice & Caniato, 2003). There are three optional trajectories: a general deterioration of performance (*Step f*) potentially leading to SC failure in the light of competition (Asbjørnslett & Rausand, 2010; Pettersen et al., 2018; Pettersen & Asbjørnslett, 2019), a return to the original performance level (*Step g*) (Barroso et al., 2015; Blackhurst et al., 2011; Wu et al., 2007; Zsidisin & Wagner, 2010), or an increase in performance with a steep recovery (*Step h*) (Barroso et al., 2011; Christopher & Peck, 2004; Jüttner & Maklan, 2011; Tukamuhabwa et al., 2015). Both the potential consequences and the different recovery trajectory stress the need for concepts to deal with the source and impact of disruptions.

## 2.3 Characterization of management concepts that address supply-side threats

Various management concepts entailing different methods have been developed to intervene at different steps of escalation and control the source and/or impact of supply-side threats. In the following section, a brief overview of the most prominent concepts, i.e., SC risk management, SC event management, SC disruption management, disaster management, and crisis management, is provided.[8] Finally, general SC resilience and, subsequently, SSRES is outlined. A classification of these into three dimensions, including the targeted supply-side threat, the potential severity of the threat, as well as the addressed phase of an escalating usptream SC disruption, is illustrated in Table 2.

[8] This overview is non-exhaustive, as it outlines only the most cited management concepts to address supply-side threats. The presented concepts are primarily full SC concepts, yet all address threats that emerge from the upstream SC.

**Table 2.** Management concepts addressing supply-side threats

| | Targeted supply-side threat | Potential severity of supply-side threat | Phase of escalating SC disruption |
|---|---|---|---|
| **SCRM** | risk | low, medium, high | before |
| **SCEM** | disturbance | low, medium | before, during |
| **SCDM** | disruption | high | during, after |
| **DM** | disruption | high | during, after |
| **CM** | disruption | high | during, after |
| **SCRES** | risk, disturbance, disruption | low, medium, high | before, during, after |

Most prominently, *SC risk management* (SCRM) entails multiple strategies and methods to deal with the prevention and mitigation of risks from the upstream SC (Hale & Moberg, 2005; Heckmann et al., 2015; J. Wang et al., 2016). More specifically, SCRM can be defined as "an inter-organizational collaborative endeavor utilizing quantitative and qualitative risk management methodologies to identify, evaluate, mitigate and monitor unexpected macro and micro level events or conditions, which might adversely impact any part of a supply chain" (Ho et al., 2015, p. 5).[9] Applying the terminology from Section 2.2, SCRM mainly deals with preventing risks from turning into disturbances and is therefore applied before a disruption. Methods for risk identification and evaluation include probability-impact assessments (see Figure 5), Value at Risk (VaR) calculations (Linsmeier & Pearson, 2019), process maps (Hallikas et al., 2004), and fault tree analyses (W. S. Lee et al., 1985). Subsequent practices for risk mitigation and monitoring include backup suppliers and excess inventory of critical parts (Simchi-Levi et al., 2018). In contrast to technical systems, SCRM does not strive for 100% reliability due to subjectivity limitations and the contradiction between objective risk (based on empirical validation) and subjective risk (perception of practitioners). As different experience levels and backgrounds can change the perception of risk, SCRM practices and methods typically should not strive for unique optimal solutions, but instead allow for the formulation of options evaluated on different criteria (Sheffi, 2005b). While SCRM is considered highly effective at countering risks with empirical data, it is considered ineffective for assessing risks with low probability, i.e., negligible and disruptive risks according to Figure 5 (Pettit et al., 2013). This is due to its event-specific nature, where the risk

[9] A clear distinction between SCRM as a *concept* with an associated body of methods and constructs and SCRM as a *research stream* as described in Section 2.4 is made.

identification and evaluation in SCRM are based on 'imaginable' risks of which knowledge exists either through experience or transfer (Taleb, 2007). The derived mitigation practices then address those specific risks directly. Considering that SCRM addresses mainly operational risks (LI/HP and HI/HP), it can be stretched across all severity degrees of resulting disruptions.

*Supply chain event management* (SCEM) entails the coordination and control of information flows in an SC (Hunewald, 2005). Its goal is to optimize the timing of communication flows and to be able to track goods movements and services and react to certain types of events early and interactively. SCEM can be used for providing early warnings for risks occurring in the upstream SC through deviation signals (Heusler et al., 2006). SCEM deals solely with the phase before the disruption and—in parts—during the disruption, where deviation signals for appropriate adaptation and response are vital (Bretzke et al., 2002). In the context of supply-side threats, SCEM's main focus is on the identification of disturbances and the communication to the relevant stakeholders to introduce countermeasures. However, events can have not only a negative but also a positive character: While negative events indicate failures in the process chain (e.g., "transport is four hours late"), positive events signal that a process has been implemented better or faster than planned (e.g., "due to additional transport capacities, a shipment can be delivered today instead of tomorrow") (Heusler et al., 2006). In either way, any type of deviational event requires subsequent action to deal with it.

Furthermore, *supply chain disruption managemen*t (SCDM) is a management concept that deals with the discovery of a disruption when it occurs and the recovery from the disruption after it has occurred (Azadegan et al., 2020; Blackhurst et al., 2005; Craighead et al., 2007; Macdonald & Corsi, 2013). Therefore, SCDM is mainly anchored in the during-disruption and post-disruption phases. Discovery is focused on becoming aware of a disturbance that will turn into a disruption. Speed in recognizing the disturbance is essential, as decision-makers can then decide whether to focus on restraining the disruption damage or on recovering to the original state. SCDM outlines the mobilization between disturbance and disruption to recover as quickly as possible. Key components of the recovery process include implementation (Helferich & Cook, 2002), anointment of decision-makers as a disruption task force (Dubrovski, 2010), and the evaluation of recovery options (Macdonald & Corsi, 2013). In general, SCDM is relevant only for disruptions with at least medium severity.

Furthermore, *crisis management* (CM) has become an established concept on an organizational level, which, in order to dive deeper, requires a definition of a company crisis: "A company crisis can be defined as a short-term, undesired, unfavourable and critical state in the company, which has derived from both internal and external causes and which directly endangers the further existence and growth of the company" (Dubrovski, 2010, p. 1199). In general, crisis management follows two distinct objectives: survival, i.e., the stopping of adverse trends and handling of the crisis situation, and re-directing, i.e., the process of securing foundations for recovery (Dubrovski, 2016; Fink, 1986; Müller, 1986). While this is similar to the definition of disruption management, and a crisis can be regarded as an extreme type of disruption, CM can be categorized as an extreme subset of SCDM, addressing disruptions with high severity during or after they have occurred.

*Disaster management* (DM) is mostly applied in the context of humanitarian logistics, where governments and NGOs build emergency SCs to supply the population with necessary means to overcome the consequences of disasters (Shareef et al., 2020). Disasters include mainly threats such as hurricanes, flash floods, fire, and famine, which may lead to loss of life, damage to infrastructure, disruption of production, and psychological after-effects (W. N. Carter, 2008). Like CM, disaster management can be mainly classified as a concept addressing the during- and post-phase of highly severe disruptions.

These five concepts, while often applied and discussed in literature and practice, each address a unique supply-side threat, phase, and severity type of a supply-side disruption. However, none of these concepts address all three phases of a disruption of all severity degrees in an integrative and holistic manner.

**Supply chain resilience**

The term resilience originally stems from the Latin "resilio", which can be roughly translated as "jump back" or "bounce back" (Klein et al., 2003; Ne Graveline & Germain, 2022). The concept of resilience appears in several scientific disciplines, including ecology, engineering, and system sciences (Vahanvati & Rafliana, 2019).

In an ecological setting, resilience refers to the *capability* of an ecosystem to respond to a perturbation or disturbance by resisting damage and adapting in case irreversible change is done (Liao, 2012). Multiple 'state valleys' are defined in relation to a stable state, without judging the quality between states. An external impulse causes a state deviation. Depending on resilience, the ecosystem enters a new state after a period of instability.[10] In an engineering setting, resilience refers to the *capacity* of a material to handle strain (Buehler & Keten, 2008). Mathematically, it describes the integral of the stress-strain curve as long as the material is still in an elastic and thus reversible state (Shuai et al., 2011). Lastly, resilience in system sciences describes the transformation and adoption of systems and the development of alternatives as an ongoing process (Berkes & Ross, 2012; Folke, 2006). Due to the wide use of the term resilience, a definition is needed that can map the term's different characteristics and meanings (Vahanvati & Rafliana, 2019), such as the definition by the United Nations Office for Disaster Risk Reduction, which states that resilience is "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions" (UNISDR, 2009, p. 24).

Unexpected disturbances like the terrorist attacks of 9/11, the Japanese earthquake, the outbreak of SARS-CoV-2, and the Russian-Ukrainian war caused severe SC disruptions and led to an emergence of resilience research in the business and SC context (Christopher & Peck, 2004; Nafday, 2011). Since then, a growing body of literature with associated definitions on the resilience of companies and SCs has emerged (Alberts, 2011; Ates & Bititci, 2011; Blackhurst et al., 2011; Carvalho, Azevedo, et al., 2012; Carvalho, Cruz-Machado, et al., 2012; Christopher & Peck, 2004; Jüttner & Maklan, 2011; Lengnick-Hall et al., 2011; Ponomarov & Holcomb, 2009; Ruiz-Martin et al., 2018). A complete overview of the most cited definitions is provided in Table 3.

**Table 3.** Resilience definitions from literature with different levels of analysis

| Source | Level of analysis | Definition of resilience |
|---|---|---|
| Christopher & Peck (2004) | System | "It is the ability of a system to return to its original state or move to a new, more desirable state after being disturbed." |
| Ponomarov & Holcomb (2009) | Supply chain | "The adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function." |
| Alberts (2011) | Firm | "Resilience provides an entity with the ability to repair, replace, patch, or otherwise reconstitute lost capability or performance (and hence effectiveness), at least in part and over time, from misfortune, damage or a destabilizing perturbation in the environment." |

[10] An example for this is a tree subject to a series of storms and entering a new and irreversible "crooked" position. In the case of light winds, the tree would have flexibly reverted to its original state (Pan et al., 2022).

| | | |
|---|---|---|
| Ates & Bititci (2011) | Firm | "The capacity of an organization to survive, adapt and sustain the business in the face of turbulent change." |
| Blackhurst et al. (2011) | Firm | "It is the firm's ability to absorb disruptions or enables the supply chain network to return to state conditions faster and thus has a positive impact on firm performance." |
| Jüttner & Maklan (2011) | Supply chain | "The apparent ability of some supply chains to recover from inevitable risk events more effectively than others." |
| Lengnick-Hall et al. (2011) | Firm | "A firm's ability to effectively absorb, develop situation-specific responses to and ultimately engage in transformative activities to capitalize on disruptive surprises that potentially threaten organizational survival." |
| Carvalho, Azevedo et al. (2012) | Firm | "A company's SC resilience is the ability of a company to avoid or minimise the occurrence of failure modes after a disturbance occurrence." |
| Carvalho, Cruz-Machado, et al. (2012) | Supply chain | "SC resilience is concerned with the system ability to return to its original state or to a new one, more desirable, after experiencing a disturbance." |
| Ruiz-Martin et al., (2018) | Organization | "The measurable combination of characteristics, abilities, capacities or capabilities that allows an organization to withstand known and unknown disturbances and still survive." |

Notwithstanding the existence of many definitions, SC resilience is united by a similar idea: it can be defined as the set of capabilities of SCs to anticipate, respond to, adapt to, recover from, and learn from SC disruptions to either achieve the original or an improved performance level (Adobor & McMullen, 2018; A. Ali et al., 2017; Hosseini et al., 2019; Kochan & Nowicki, 2018; Ponomarov & Holcomb, 2009; Sheffi, 2005a).[11] Resilience can be therefore categorized as a concept that is relevant before, during, and after a disruption and can tackle all kinds of disruption severity (see Table 2). Since SCs are networks of companies (Essig et al., 2013), it is essential that each adopt individual capabilities to prevent damage from disturbances and recover quickly (Carvalho, Cruz-Machado, et al., 2012).

The concept of SC resilience can be studied from three different perspectives: (1) network perspective, (2) supply-side perspective, and (3) demand-side perspective. Also known as SC network resilience (SCNR), the network perspective focuses on the overall SC network (Borgatti & Li, 2009; Li & Zobel, 2020). This perspective is underpinned by the view that the scope of competition has extended company boundaries to entire SCs (Lambert et al., 1998), and therefore argues that the capacity of the entire network

[11] Similar to the ecological and engineering settings, resilience in an organizational or supply chain context can traditionally be regarded as a state dimension expressed through its capabilities. Some authors mention SCRES as a management discipline that identifies, selects, evaluates, renews, and, more generally, manages these capabilities. For the present dissertation, these terms will be used interchangeably.

to deal with disruptive risks and resulting disruptions needs to be studied (Kim et al., 2015; Li & Zobel, 2020; Zhao et al., 2011). A comprehensive view of network resilience helps explore the individual companies' systemic risks (Li et al., 2020). The literature taking this perspective is mostly quantitative and generally utilizes two different approaches; the first approach includes traditional operations research models of networks, with optimization of nodes and links to be included (Basole & Bellamy, 2014; Kim et al., 2015; Zhao et al., 2011). The second approach provides insight into how the network structure influences resilience. However, these approaches generally have limitations in terms of real-world applicability (Li et al., 2020). With each additional tier in SCs, the guarantee of individualized insights for company-level decision-making becomes challenging.

Furthermore, the supply-side perspective of SC resilience constrains the scope of study to addressing upstream SC disruptions from the perspective of a focal company. So far, some research has been conducted on resilience applied in this context. After Pereira et al. (2014) explored the context of resilience in PSM with an extensive literature review, the term "supply-side resilience" (SSRES) was coined (Pereira et al., 2020).[12] Building on this definition to extend to the upstream SC, SSRES can be defined "as the capability of a buying firm to prepare for, respond to and recover from unexpected upstream SC disruptions by returning to, or maintaining continuity of, operations at the desired level of connectedness and control over structure and function" (Dabhilkar et al., 2016, pp. 949–950). The relevance of SSRES is mainly driven by two factors. One is that most disruptive risks originate upstream of the SC and escalate downstream (Ivanov et al., 2019; Nitsche & Durach, 2018). As an interface with the upstream SC, buyers play a central role in managing resources to address disturbances. The second factor is that the procurement function in MCs has continuously gained in importance for managing resources (see Section 2.1). This combination of factors makes SSRES a vital concept to investigate.

Finally, demand-side resilience (DSRES), downstream resilience from the perspective of a focal company, is a highly under-researched topic. While it is accepted that demand shocks can play a central role in disruptions, not much research has been conducted to characterize these shocks (Lu et al., 2021). Most literature has focused on the ripple

[12] This term will be used for the remainder of the present dissertation.

effects of disruptions on downstream SCs, such as missing materials and production decrease (Ivanov et al., 2019). The DSRES has been mainly concerned with downstream visibility-related risk mitigation strategies, i.e., silent product roll-over, responsive pricing, collaborative forecasting, and vendor managed inventory (Seifert & Lücker, 2014). These strategies mainly aid in preventing stockouts (Friday et al., 2021).

For the present dissertation, SSRES will be the main concept of analysis. As most research has been conducted about general SC resilience, insights from the network perspective will aid in conceptualizing the supply-side perspective, especially throughout the literature review in Sections 3.1 to 3.3.

## 2.4 Characterization of supply-side resilience operationalization for MCs

The following section is dedicated to structuring the field of SSRES operationalization by MCs. First, an overview of the most relevant literature streams for this topic are provided. Second, the multiple levels of SSRES are demarcated. Third, SSRES operationalization by MCs is conceptualized by drawing on the literature.

**Overview of the relevant research streams for the research topic**

Over the past two decades, research on SC resilience has yielded an extensive body of literature that is deeply rooted in the domain of *supply chain risk management* (Brusset & Teller, 2017; Elleuch et al., 2016; Fiksel et al., 2014; Kleindorfer & Saad, 2005; Peck, 2016).[13] This dissertation is mainly anchored in it. The research domain clearly differs from the methods described in Section 2.3. Due to the specific focus on procurement and its operationalization, two additional research streams are touched upon: *purchasing and supply management* and *strategic cost management*. These streams are outlined in the following section, including potentially relevant sub-streams and their relation to the present research. An in-depth analysis of research on SSRES operationalization is provided separately in Chapter 2.

*Purchasing and supply management (PSM)* is the research stream dedicated to "the alignment of organizations, processes, and systems for strategic sourcing, contract management, supplier management, [and] spend analysis to continuously improve global

[13] A distinction between SCRM as a research stream and as a concept is made. The latter is outlined in Section 2.3.

supply for best-value performance in support of the strategic objectives of the business" (Burt et al., 2003). While PSM research has significantly developed both empirically and conceptually in light of the ever-growing strategic relevance of the procurement function (see Section 2.1), it cannot be considered an established scientific discipline, mainly due to the lack of development of tested theories from within the field (Harland et al., 2006; Spina et al., 2016). Nonetheless, PSM is a stand-alone academic discipline within the broader field of SCM focused on the upstream supply network (Bals et al., 2019; Spina et al., 2016). Several studies within PSM have been dedicated to investigating the intra- and inter-organizational issues falling under the responsibility of procurement to create SSRES (Pereira et al., 2014).

Furthermore, the fundamental research stream of *strategic cost management* is key to understanding the monetary evaluation of SSRES operationalization. At the core of this stream lies the development and application of cost management techniques to "simultaneously improve the strategic position of a firm and reduce costs" (Cooper & Slagmulder, 1998). In general, PSM is "held highly accountable for the delivery of cost savings in all of the organizations" (Ellram, 2002, p. 13). Additionally, "effective cost management is not a one-off approach that the company takes when it really needs to reduce its costs, but an ongoing expectation that is built into supplier relationships and the organization's reward and measurement system" (Ellram, 2002, p. 14). As strategic cost management plays a decisive role in allocating resources to gain a competitive advantage (Cooper & Slagmulder, 1998), many companies apply techniques such as Total Cost of Ownership (TCO) (Ellram, 1995), Life-Cycle Costing (LCC) (Dhillon, 1989), and Activity-Based Costing (ABC) (Cooper & Kaplan, 1991) to calculate and track costs for specific investment decisions. In the context of this dissertation, these investment decisions include procurement decisions such as supplier selection (Roodhooft & Konings, 1997) or make-or-buy decisions (P. F. Johnson et al., 2011). Next to tracking costs, an integral sub-stream of strategic cost management ensures that investments into projects achieve a positive return. Therefore, techniques from this research stream will be helpful in conducting CEAs for the adoption of SSRES practices.[14] As one of the main feasibility evaluation methods for projects in PSM (Ellram, 2002), CEAs entail cost describing the necessary expenditure and effectiveness describing the extent to which an

[14] Complementary to cost-benefit analyses and often used in the medical context (Lansdorp-Vogelaar et al., 2011; Owens, 1998), CEAs are used when the benefits are not quantifiable in monetary terms.

objective was reached by a project. Giunipero and Eltantawy (2004) agree that “the total cost of an undesirable event occurring needs to be evaluated in comparison to the benefits realized from having strategies in place that significantly reduce the chance and/or effects of detrimental events with supply” (Giunipero & Eltantawy, 2004, p. 710). CEAs thus provide the foundation for decision-makers to make rational practice adoption decisions and redirect resources for higher effectiveness.

Figure 7 illustrates the relevant research streams that are deemed relevant to this dissertation. A clear delimitation of the literature into the individual research streams is not always possible, as there is often high overlap.

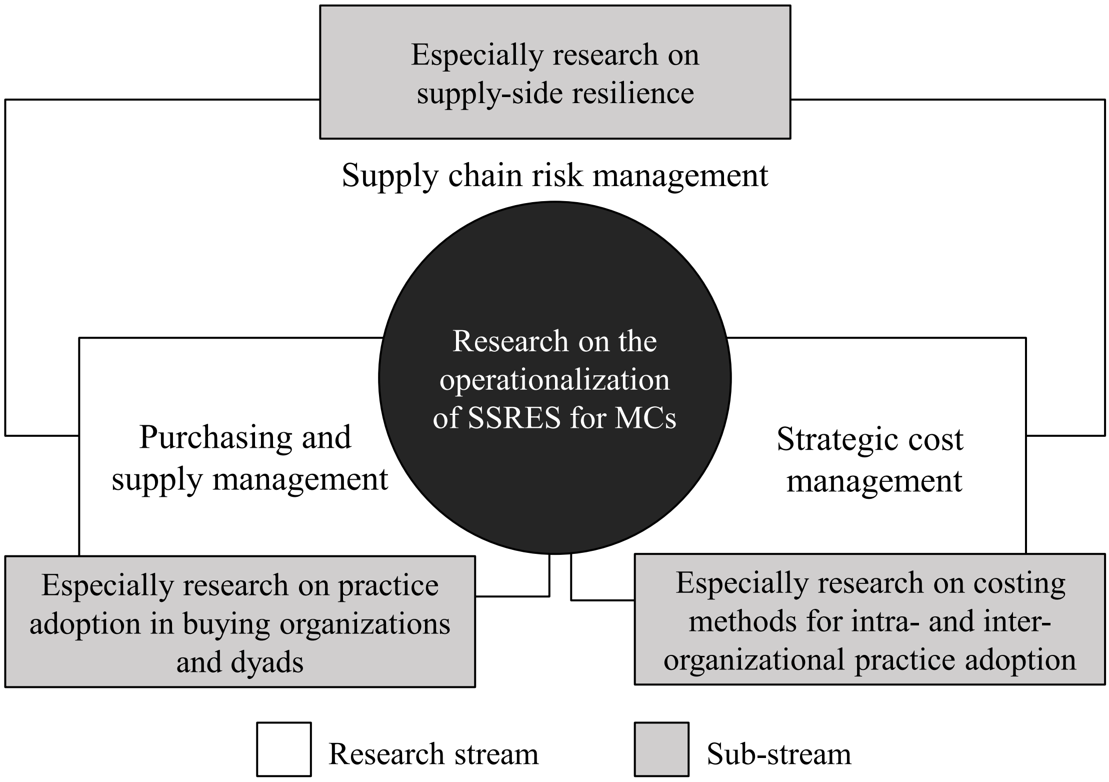


**Figure 7.** Overview of the relevant research streams for research on the operationalization of SSRES for MCs

### Delimitations for studying SSRES operationalization

The adolescence of the research field including highly focused studies on various aspects of the SSRES operationalization has led to a fragmented body of literature that is difficult to grasp. Different perspectives for studying the subject must be distinguished to ensure common understanding, in terms of the unit of analysis and unit of observation. The literature reveals three different perspectives: focal company, dyad, and network.

The focal company is chosen as the unit of observation. As SSRES operationalization requires the breakdown of SSRES into practices which may also require collaboration and incentivization models for tier 1 suppliers, the dyadic view is considered in rare cases, however, the research is mainly focused on the adopted practices by the focal company. This research considers disruptive risks and their resulting escalation into disturbances and disruptions (see Section 2.2). These risks mostly occur upstream and escalate downstream. The management level that is considered is of operational and tactical nature, rather than strategical nature, as the concretization of SSRES as a concept and groundwork for the decision to adopt operational practices is of primary focus. A summary of the delimitations of the dissertation project is presented in Table 4.

**Table 4.** Delimitations of the dissertation

| **Category** | **Manifestation** | | | |
|---|---|---|---|---|
| **Unit of observation** | focal company | dyad | network | |
| **Company unit** | manufacturer | retailer | service provider | others |
| **Risk type** | negligible | operational | disruptive | |
| **Risk origin** | upstream | intra-firm | downstream | |
| **Management level** | operational | tactical | strategical | |

Operationalization describes the transformation from an abstract concept into quantitative, measurable observations (Weaver, 2008). The traditional steps for operationalization are as follows: (1) identification and conceptualization of idea to operationalize, (2) selection of variables to represent the whole concept or parts of the concept, (3) selection of measures for each variable, (4) interpretation of the measure (Engel & Schutt, 2014). While operationalization for some concepts might seem straightforward (e.g., customer loyalty), other concepts suffer from a high abstraction level (e.g., creativity) (Roskam, 1989).[15] Multidimensional concepts can be measured through indexes, scales, and typologies (Engel & Schutt, 2014; Weaver, 2008). While operationalization helps build an empirical foundation for certain concepts, it may be limited in terms of underdetermination and reductiveness, resulting in a lack of generalizability to different contexts (Weaver, 2008). This dissertation attempts to remedy this issue by translating SSRES for MCs from an abstract aggregation of constructs to an integrative, measurable concept

[15] For example, customer loyalty could be measured by customer retention or ratings on a questionnaire. Creativity, however, may be measured through experiments with a high degree of context factors.

with entailed managerial practices. An ideal-typical operationalization process of SSRES in the form of a CEA for practices is illustrated in Figure 8 with an allocation of the managerial challenges from Section 1.1. An *interim conclusion* is drawn:

*The ideal-typical process of SSRES practice adoption comprises the stages of operationalization and execution, which are separated by the decision of whether to adopt a practice or not. This dissertation is mainly anchored in the first stage of this process, which entails the conceptualization of SSRES, including the identification of practices and the evaluation of these practices in terms of effectiveness and cost measurement. The latter two are required to conduct a systematic CEA that is vital for the subsequent decision of adoption. In the second stage, which is beyond the scope of this dissertation, the actual execution of adoption, including planning, implementation, and controlling, are conducted. While the first stage occurs mainly on a company level, the second stage may include the tier 1 supplier.*

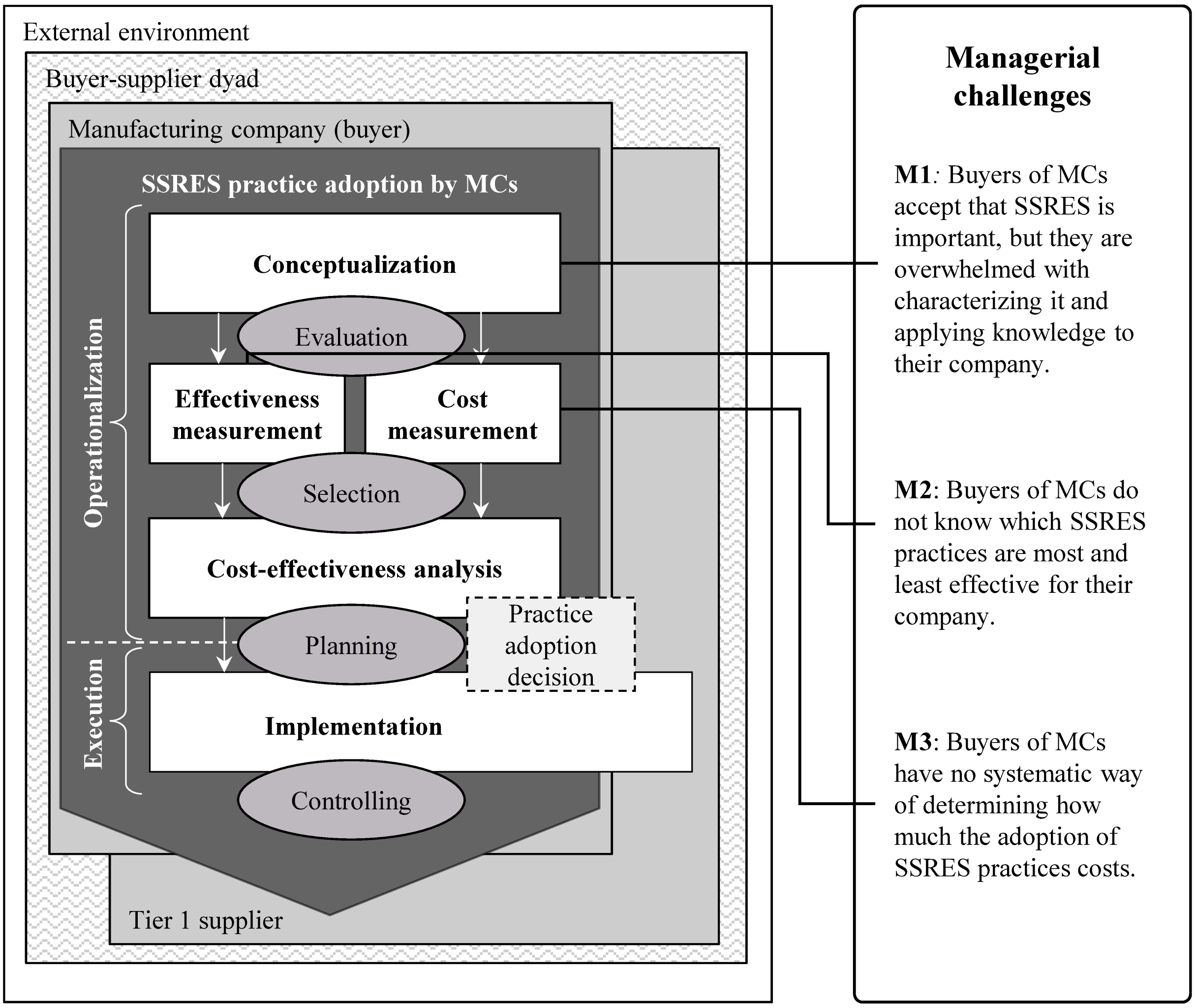


**Figure 8.** Ideal-typical depiction of SSRES practice adoption by a MC

# 3 Literature review of the research on supply-side resilience operationalization for manufacturing companies

This chapter provides a literature review of state-of-the-art research on the SSRES operationalization for MCs. First, an overview of the literature around the characterization of SSRES practices is examined (Section 3.1). Second, the research on measuring the effectiveness of SSRES practices is outlined (Section 3.2). Finally, research on costing SSRES practices with monetary metrics is provided (Section 3.3).

## 3.1 Overview of the research on conceptualizing supply-side resilience

In this section, the literature on conceptualizing SC resilience on a more general level is presented. Building on this, conceptualization of SSRES is undertaken.

Within SCRM literature, multiple studies have attempted to conceptualize SC resilience. These attempts break down SC resilience into intermediary constructs with differing levels of abstraction (A. Ali et al., 2017). Constructs can be classified into higher-order constructs (i.e., phases, strategies, capabilities, factors, principles, competencies, enablers, objectives, elements, etc.) and lower-order constructs (i.e., practices, activities, etc.). While the higher-order constructs have the highest level of abstraction, the lower-order constructs are the most concrete. Most studies in SCRM research address higher-order constructs. The SC resilience framework by A. Ali et al. (2017) – relying on the analysis of 103 publications to build a concept mapping framework[16] – illustrates the relationships between higher-order constructs (i.e., *phases*, *strategies*, *capabilities*, and *elements*) and lower-order constructs (i.e., *practices*) (A. Ali et al., 2017). In the following study, this framework will be used to guide the review of literature.

The highest-order construct encompasses the three chronological *phases* of SC resilience, namely the phase before the disruption (pre-disruption[17]), the phase during the disruption (during-disruption), and the phase after the disruption (post-disruption)

[16] A concept map is a graphical tool for visualizing theory and concepts and their interrelationships. The systematic representation helps organize knowledge on a topic and is usually created and read from top to bottom in a hierarchical arrangement (Novak & Cañas, 2006).
[17] In the context of this dissertation, the term *pre-disruption* is an umbrella term for chronologically including both the pre-disturbance and the during-disturbance phase before escalating into a disruption.

(Christopher & Peck, 2004; Rice & Caniato, 2003; Sheffi & Rice, 2005). This view corresponds with the chronology of a disruption from Section 2.2.

Three different SC resilience *strategies* can be assigned to the three SC resilience phases described (Hollnagel, 2010). Before the disruption, a *proactive* strategy is used, which focuses on the preparation and planning of unforeseeable changes in the environment (Ambulkar et al., 2015; Melnyk et al., 2014; Ponomarov & Holcomb, 2009). In the phase during the disruption, the *concurrent* strategy becomes relevant, involving rapid reactive thinking and initial response to cope with the disruption events and their negative impacts (Scholten et al., 2014; Sheffi & Rice, 2005). Together with the proactive strategy, the concurrent strategy's main objective is the mitigation of damage (Tang, 2006). Ultimately, a *reactive* strategy in the post-disruption phase serves to cope with the changes and adapt accordingly (Schmitt & Singh, 2012). The main objective of the reactive strategy is the maximization of recovery speed (Melnyk et al., 2014).

Terms such as capacity, ability, and capability to describe the skills within strategies that enable organizations and SCs to effectively deal with disruptions have been used interchangeably (Madani & Parast, 2021); for this dissertation, the term *capabilities* will be used as the third construct. Based on the three SC resilience strategies, five main categories of capabilities can be identified. The *capability to anticipate* includes proactive skills required to perceive, recognize, and constantly monitor potential adverse events, a changing environment, or deviating performance before SC performance is compromised (Hollnagel, 2010; Wieland & Wallenburg, 2013). The *capability to adapt* includes concurrent capabilities that are required during normal operations or during a disturbance and or disruption to consistently manage and adapt critical SC resources (Ambulkar et al., 2015). Also, the *capability to respond* represents concurrent capabilities in the phase during the disturbance or disruption and is required to respond to the disturbance in a timely and efficient manner (Hollnagel, 2010). The goal is to minimize adverse effects or, in the best case, transform the effects into benefits (A. Ali et al., 2017). The *capability to recover,* as well as the *capability to learn,* are classified as reactive capabilities (Blackhurst et al., 2011; Jüttner & Maklan, 2011). The former contains those capabilities that enable organizations to return to or restore a stable operating state after a disruption/interruption. The latter refer to those capabilities that are required to understand what has happened, as well as learn from the experience and grow as a company from it (A. Ali et al., 2017).

SC resilience *elements,* as the fourth construct, support and enhance SC capabilities. The relevant literature includes several terms that can be attributed to the construct of elements, including dimensions (Durach et al., 2015), enhancers (Blackhurst et al., 2011), and enablers (Pereira et al., 2014). To maintain consistency, the term *elements* is used in this dissertation (Christopher & Peck, 2004; Hohenstein et al., 2015). Furthermore, managerial practices were identified as the fifth and most operational construct that build and uses the capabilities, yet the term "practice" was not defined. In the following, succinct summaries of each element are provided with associated practices.

The first five elements and their associated practices can be allocated to the proactive SC resilience strategy and its required capability to anticipate. *Situation awareness* involves understanding the uncertainties in the SC and preparing and planning for potentially adverse events (Priya Datta et al., 2007). Applicable practices include capturing and interpreting events, developing early warning strategies and continuity planning, and risk avoidance and mitigation (Manuj & Mentzer, 2008; Sáenz & Revilla, 2014; Stecke & Kumar, 2009). *Robustness,* as the second element, refers to an organization's ability to withstand a disturbance and maintain planned performance (Nair & Vidal, 2011; Simchi-Levi et al., 2018). In this regard, building resilience requires SC network design practices and includes SC and critical location configuration (Knemeyer et al., 2009), product design (Khan et al., 2012), and SC network density and complexity configuration (Craighead et al., 2007), among others. The element of *visibility* acts as a warning strategy by providing time for an organization to align its capabilities to minimize the impact of an adverse event (Stecke & Kumar, 2009). Practices used here include the use of performance monitoring metrics (KPIs) (Ambulkar et al., 2015; Melnyk et al., 2014), investment in IT capabilities supporting increased information sharing, and increased visibility through integrated systems (Brandon-Jones et al., 2014; Jüttner & Maklan, 2011). *Building security,* the fourth element, needs to be designed proactively and protects the SC from intentional attacks (Rice & Caniato, 2003; Sarathy, 2006). This element takes the form of practices such as cyber and freight security (Stevenson & Busby, 2015), the creation of a security culture, and collaborative strategies with members of the SC (Bakshi & Kleindorfer, 2009). Cultivating *knowledge management* in the pre-disruption phase can be improved through practices such as training and drills, simulations, and exercises, creating a SCRM and SC resilience culture, and cross-organizational learning (Blackhurst et al., 2011; Jüttner & Maklan, 2011; Pettit et al., 2013; Scholten et al., 2014).

In the second phase during the disruption, concurrent elements 6 through 9 and their practices come into play. Increasing *flexibility* ensures that when disruption/disruption occurs, organizations adapt quickly and easily to the changes and absorb them with effective response (Skipper & Hanna, 2009). Flexibility can be increased using various practices such as flexible manufacturing processes and resources, maintaining a flexible transportation mode, and flexible supply through multiple suppliers (Azevedo et al., 2013; Tang & Tomlin, 2008; Zsidisin & Wagner, 2010). Building *redundancy*, as the seventh element, primarily involves maintaining excess capacity and improves adaptability to unpredictable environmental changes (Rice & Caniato, 2003). Applicable practices include using excess capacity in production (Sheffi & Rice, 2005; Stecke & Kumar, 2009), transportation (Stecke & Kumar, 2009), or resources (Ratick et al., 2008), building a safety stock (Wu et al., 2013), and including multiple suppliers as back-up (A. Ali et al., 2017). *Collaboration* refers to working vertically and horizontally with SC members to respond to a disruption/interruption in a prompt and coordinated manner. The practices required include collaborative planning (Christopher & Peck, 2004) and information sharing (Jüttner & Maklan, 2011; Pettit et al., 2013). The ninth element, *agility*, focuses on responding quickly to unforeseen events (Braunscheidel & Suresh, 2009). This element is associated with practices such as responsiveness (Ivanov et al., 2014) or acceleration (Wieland & Wallenburg, 2013).

The third phase after the disruption includes the reactive elements 10 to 13 and their associated practices. Post-disruption *contingency planning* is used to initiate appropriate actions to recover from a disruption as quickly as possible (Melnyk et al., 2014). The practices required for this include resource and SC reconfiguration (Blackhurst et al., 2011), scenario analysis (Colicchia et al., 2010), or the development of regeneration plans (Fiksel, 2015; Gong et al., 2014), among others. The eleventh element includes the *market position* or the positioning of a company in the market (Fiksel, 2015). The practices related to this element include increasing market share (Pettit et al., 2010), improving organizational efficiency (Ponomarov & Holcomb, 2009), and strengthening corporate financial strength (Sheffi & Rice, 2005). *Post-disruption knowledge management* refers to a company's ability to learn from the events and related experiences (Rice & Caniato, 2003). Practices that can be applied for this purpose are divided into education and training, an increase in innovation capability in the context of contingency planning and continuity management (Golgeci & Ponomarov, 2013), and obtaining feedback after the disruption/interruption (Blackhurst et al., 2011), among others (A. Ali et al., 2017). The last element involves *building social capital* between SC members and other entities, with the goal of strengthening the ability to learn from each other (N. Johnson et al., 2013). The element is promoted through practices such as building inter-organizational relationships and trust and leveraging co-creation processes (A. Ali et al., 2017).

Little research has been conducted so far to identify resilience constructs specifically within the responsibility sphere of PSM, i.e., SSRES constructs; only three studies could be identified to this end. Pereira et al. (2014) were the first to put SC resilience in the context of PSM, identifying the procurement function as essential to managing SC resources. Their literature review reveals those higher-order constructs (i.e., enablers and barriers) of SC resilience most cited in PSM literature. Their findings reveal a positive influence of seven higher-order constructs (flexibility, redundancy, visibility, agility, collaboration, integration, and information sharing) on “procurement activities” (Pereira et al., 2014). In their multiple case study, Pereira et al. (2020) examine buyer-supplier dyads in the Brazilian manufacturing industry and compare those resilience practices mentioned in literature to those in expert interviews. After categorizing the identified seven proactive practices and seven reactive practices, they conclude that customization across three dimensions determines an SSRES strategy: nodes (e.g., pick-up points), edges (e.g., means of transport), and general conditions (e.g., toll systems) (Pereira et al., 2020).

Finally, Dabhilkar et al. (2016) explain SSRES as a set of practice bundles of the buying organization, each categorized in dichotomous capability dimensions across time (proactive/reactive) and space (internal/external). The latter two studies theoretically underpin their findings with the dynamic capabilities view (DCV), however, both lack rigor in its application: DCV underlies the assumption that the unit of observation is inspected at least twice: once before the disruption and once after the disruption; ideally, another observation point during the disruption could aid insight generation. However, this is not the case in either study. In fact, Arend & Bromiley (2009) comment that “despite the dynamic structure of DCV, only a minority of the studies used longitudinal, time series data” (Arend & Bromiley, 2009, p. 85).

Notwithstanding the breadth of literature identifying higher-order and lower-order constructs for characterizing SC resilience and SSRES, practices in literature remain abstract. A. Ali et al. (2017) names “sensing and interpreting events”, “supply chain/infrastructure configuration”, and “velocity and acceleration” as practices. Furthermore, Pereira et al. (2014) mentions activities such as “supplier base”, “network configuration”, and “risk sources”. Taking Bromiley & Rau’s (2014) definition into account, a practice consists of a set of activities. These practices are generalizations of specific case studies or literature reviews, and as such they leave room for interpretation when deriving concrete activities. Generally, the abstraction level of mentioned managerial practices widely differ with descriptions such as tasks (N. P. Carter et al., 2010), processes (Scholten et al., 2014), investments (Melnyk et al., 2014) and activities (Pereira et al., 2014), pointing to a lack of stringency among authors. The breadth in literature engenders a lack of precision regarding the concretization of utilizable and understandable practices, automatically leading to a weak linkage between higher-order and lower-order constructs.

Considering the constructs and relationships between them, some authors have researched moderating contingency variables on adoption and optimization resilience practices. Identified variables include product complexity (Eckstein et al., 2014), resources (Brandon-Jones et al., 2014), network complexity (Chowdhury et al., 2019), and disruption types (Wong et al., 2020). While the moderating effect of these variables has been validated individually, research lacks a holistic analysis deriving a set of company-internal and external variables.

## 3.2 Overview of the research on evaluating effectiveness of supply-side resilience practices

Having outlined the literature on theoretical constructs of SSRES, this subsection is dedicated to the evaluation of effectiveness of SSRES practices for a specific context. The literature for this overview is placed in three different sub-streams. The first sub-stream is dedicated to the measurement of SSRES as a state through proxy KPIs. The second sub-stream is focused on the measurement of higher-order SSRES constructs (e.g., capabilities, elements) as alone-standing concepts. The final sub-stream addresses the effectiveness of lower-order SSRES constructs (e.g., practices, activities) towards achieving SSRES. For each sub-stream, an overview of the (a) measurement metrics and the (b) measurement methods are outlined. An overview of the three streams is provided in Figure 9.

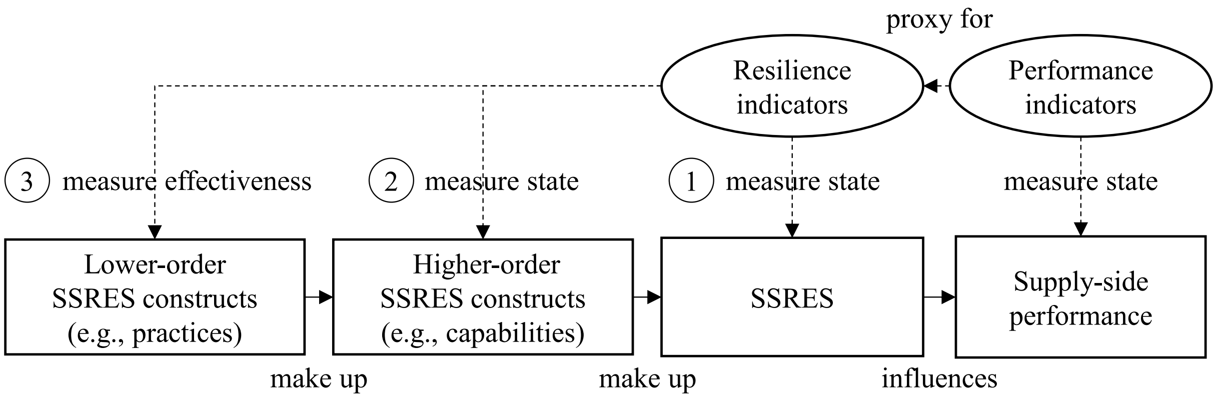


**Figure 9.** Structure of literature sub-streams on the effectiveness of SSRES practices.

The first sub stream deals with the formulation of SSRES proxy KPIs and their use by measurement of a resilience state before, during, and after a disruption. Cashflow-related KPIs such as stock level and capacity utilization (Gunasekaran et al., 2001, 2004), and profit margin (Carvalho et al., 2011; Sheffi, 2005a) are commonly used metrics. Furthermore, this category includes KPIs from the perspective of the buyer linked to specific supplier performance. These include the quality of delivered goods (Chan, 2003), order lead time (Carvalho, Barroso, et al., 2012; Wu & Blackhurst, 2009), on-time delivery of goods (Carvalho et al., 2011; Cavalcante et al., 2019; Hallgren & Olhager, 2009; Ivanov, 2020; Wagner, 2008), and revenue through the supplier (Ivanov, 2018; Zavala et al., 2018). Further supplier-specific KPIs such as supplier delivery efficiency (Gunasekaran et al., 2004) and supplier rejection rate (Huang & Keskar, 2007) have been noted. The full overview of KPIs as SSRES metrics is provided in Table 5.

**Table 5.** Proxy KPIs for measuring SSRES

| SSRES proxy KPI | Perspective | Target | Exemplary source |
|---|---|---|---|
| **Stock level** | Buyer | Buyer | Gunasekaran et al. (2004) |
| **Capacity utilization** | Buyer | Buyer | Gunasekaran et al. (2001) |
| **Profit margin** | Buyer | Buyer | Carvalho et al. (2011) |
| **Quality of delivered goods** | Buyer | Supplier | Chan (2003) |
| **Order lead time** | Buyer | Supplier | Wu & Blackhurst (2009) |
| **On-time delivery of goods** | Buyer | Supplier | Cavalcante et al. (2019) |
| **Revenue through supplier** | Buyer | Supplier | Ivanov (2018) |
| **Supplier delivery efficiency** | Buyer | Supplier | Gunasekaran et al. (2004) |
| **Supplier rejection rate** | Buyer | Supplier | Huang & Keskar (2007) |

Some researchers have proposed single KPIs (Carvalho, Barroso, et al., 2012; Carvalho et al., 2011; Wu et al., 2007; Zavala et al., 2018), multiple KPIs (Cardoso et al., 2015; Ivanov, 2020; Li et al., 2020), and indices to aggregate various correlated metrics (Barroso et al., 2015; Hosseini et al., 2019; Munoz & Dunbar, 2015; Pettit et al., 2013; Rajesh, 2020), oftentimes mixing financial and non-financial KPIs. Composite indices based on linear models are suited for SSRES, as long as performance indicators are without synergy and conflict effects (Barroso et al., 2015). For example, Ivanov (2020) models the impact of epidemic outbreaks and compares production-inventory dynamics, estimated lead time service level, financial performance, and lead-time performance.

Different methods of measuring SSRES with these KPIs have emerged in the last decade. While initial contributions to this sub-stream were made from probabilistic theory and stochastic programming (Klibi, Martel, et al., 2010), high uncertainty predicting the likelihood of HI/LP risks and their consequences led to a focus on event exposure (Ivanov, 2021a; Simchi-Levi et al., 2014). This implies that proactive and concurrent SSRES refers to how well a focal company or dyad could mitigate the damage of a disruption that is sure to have an impact. However, reactive SSRES is often measured by the recovery speed of a company after a disruption. Many of the existing methods to measures proactive-concurrent resilience are based on Bruneau et al.'s (2003), formula for measuring the loss of community resilience when an earthquake hits:

$$RL = \int_{t_0}^{t_1} [1 - Q(t)]\, \mathrm{d}t$$

where $Q(t)$ is the expected quality of community infrastructure at time $t$, $t_0$ is the time when the earthquake occurs, and $t_1$ is the time at which the community infrastructure has fully recovered to a stable position (Bruneau et al., 2003; Ivanov, 2021a). Furthermore, Simchi-Levi (2015) introduced a model with two notions: time-to-survive (TTS), i.e., the "maximum amount of time [an SC] can function without performance loss if a particular node is disrupted" (Simchi-Levi et al., 2015, p. 8) and time-to-recover (TTR), i.e., "the time it takes for a node to recover to full functionality after the disruption". TTR and TTS are used to "identify bottleneck suppliers for which it's critical to obtain accurate TTR information and distinguish them from other suppliers where even plus or minus 30% error in TTR information will have very little impact on the supply chain"

(Simchi-Levi, 2015). Kinra et al. (2020) extended this approach by considering the ripple effects of disruptions preceded by HI/LP risks and considering possible maximum loss.

The second sub-stream, which is mainly concerned with the state measurement of higher-order constructs, entails more qualitative studies. A wide variety of both objective and subjective metrics are used. For example, Karl et al. (2018) link SC resilience elements (e.g., flexibility, robustness, agility) to specific non-financial KPIs (Karl et al., 2018). Moreover, while multiple authors have attempted to explain SSRES capabilities through DCV (see Section 3.1), there is a lack of consensus in the literature on how to measure these capabilities (Arend & Bromiley, 2009). Critics argue that the use of measurement proxies raises doubts "about whether the measures really reflect dynamic capabilities, or even if they address the same construct" (Arend & Bromiley, 2009, p. 85). They continue by positing that "[t]raditional measurement approaches expect high correlations among different measures of the same construct, but the measures used for dynamic capabilities appear quite unrelated" (Arend & Bromiley, 2009, p. 85). The Supply Chain Resilience Assessment and Monitoring (SCRAM) tool, developed by Pettit et al. (2013), can be used to measure a company's SC resilience by aggregating the resilience gaps proposed by Pettit et al. (2010). The gaps indicate where capabilities would fail to address specific SC vulnerabilities (see Section 3.1). Using a Bayesian network approach, Hosseini et al. (2019) combine vulnerability and recoverability measures of companies in a supply network to a resilience index with ripple effect considerations. Three pre-disruption robustness measure and one post-disruption recoverability measure are proposed by Namdar et al. (2017), who argue that decision-makers should focus on key characteristics of the SC (Namdar et al., 2017). Essentially, measurement methods in this sub-stream generally do not address specific disruptions, but instead measure higher order constructs to aggregate to a general proactive-concurrent SSRES state.

The final sub-stream is concerned with measuring the effectiveness of lower-order SSRES constructs like practices and activities. Effectiveness is defined as the degree to which a practice or an activity is successful or achieving the results that one wants (Price, 1972). Often used in a military and traffic context, the measurement of effectiveness (MOE) expresses the degree to which a KPI achieves an objective (Reed & Fenwick, n.d.; Sproles, 2002) and should allow for the ranking of comparable systems (Pinker et al., 1995). What an MOE does not include is an assessment of the means utilized to adopt the practice in the first place.[18] The following characteristics must be valid for MOE: they must be related to performance indicators, must be dependent on time and tied to environmental conditions. Current efforts to find overall MOE for practices of any kind is characterized by the following challenges: (1) the quantification of subjective attributes (Singh et al., 2016) and (2) the combination of multiple performance measures explaining different attributes into a single measure (Pinker et al., 1995).

In the context of this dissertation, MOE of SSRES practices would provide insight into how successful the adoption of a practice is at the time of its usage. This corresponds to the extent to which practices help reduce damage during and increase recovery speed after the disruption with regards to a KPI (Melnyk et al., 2014; Simchi-Levi, 2015; Simchi-Levi et al., 2015). The literature currently lacks guidance on which KPIs to use for the analysis of which practice. Regarding measurement methods, authors often use scenario analysis methods to evaluate the effectiveness of practices, including the with/without principle (Hof & Rideout, 1989) or alternatives analysis (Rocco et al., 2015). "Net project benefits are the net benefits with the project, minus the net benefits without the project" (Randall, 1981, p. 287). According to this logic, the with/without principle can be "interpreted [to mean] that any individual project or output change can be evaluated independently […] by comparing its separable cost with its separable benefit." (Hof & Rideout, 1989, p. 217). During-disruption practice effectiveness describes the extent to which the adoption of a practice difference of a KPI is quelled and how much damage can be avoided (see Figure 10 on the left).

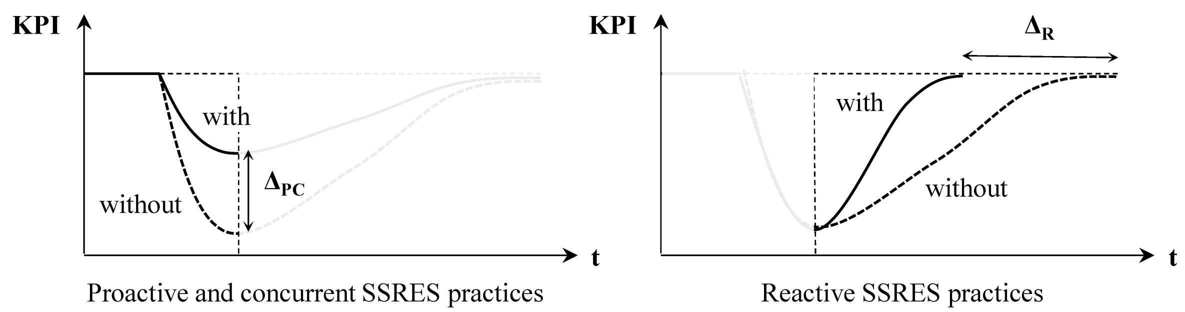


**Figure 10.** Exemplary MOE of proactive/concurrent SSRES practices (left) and reactive SSRES practices (right)

[18] *Effectiveness* stands in contrast to *efficiency*, which describes the "condition or fact of producing the results you want without waste" (Cambridge Dictionary, 2022).

For reactive practices, the time gap between full recovery after a disruption with a practice versus without a practice can be used as an MOE (see Figure 10 on the right). The values for these scenarios are either measured by empirical data or based on subjective evaluations.

Beyond scenario analysis, Dabhilkar et al. (2016) operationalize the effectiveness of SSRES practices in the buying organization through confirmatory factor analysis and regression analysis. More specifically, they estimate the strength of relationship between the resilience capability bundles (independent variable), consisting of practices, and the speed after recovery (dependent variable). Using a mixed methods approach, they translate qualitative data (i.e., interview transcripts) into quantitative data (Likert scale).

## 3.3 Overview of the research on costing supply-side resilience

An overview of the research on SSRES cost is provided in two parts: In the first part, specific resilience-related cost literature will be investigated. The second part is dedicated to methods for estimating the cost of practice adoption, maintenance, and usage.[19] While the former part is mainly obtained from SCRM literature, the latter part is extracted from the interface of PSM and strategic cost management literature.

In general, resilience cost literature is of a quantitative nature. As practitioners are interested not only in addressing HI/LP risks through resilience, but also in the economic impact of their actions, some operationalization models additionally include cost (Carvalho, Barroso, et al., 2012; Carvalho et al., 2011; Wu et al., 2007; Zavala et al., 2018). Resilience-specific cost literature reveals two sub-streams with respective cost types: (1) expected disruption cost and (2) costs resulting from investments in resilience.

The first sub-stream contains quantitative methods to evaluate the monetary damage caused by disruptions and introduce reactive mitigation measures to contain the damage (Klibi, Lasalle, et al., 2010; Snoeck et al., 2019). Different cost drivers in this sub-stream include backlog cost, damages cost, delay penalties, procurement cost penalties, recovery costs, transport costs, and transshipment costs (Aldrighetti, Battini, Ivanov, et al., 2021). For instance, Pires and Barbosa-Povoa (2018) define an objective function to both incorporate financial and non-financial indicators, i.e., the expected net present value comparatively with and without disruption. Numerous studies have measured this

[19] This subsection includes excerpts from Study C. For a more detailed examination, consult Appendix C.

damage using non-delivery penalties per fixed period of time, taking the form of elevated transportation costs and missed revenue (Jabbarzadeh et al., 2018; Riccardo et al., 2021; Snoeck et al., 2019b). However, many of these studies are concerned with the probability of disruption to estimate expected costs (Aldrighetti, Battini, Ivanov, et al., 2021; Klibi & Martel, 2012), standing in direct conflict with established resilience definitions, which assume that the HI/LP risks causing disruptions have insufficient underlying empiricism to be predicted (Pettit et al., 2010).

Studies focusing on the second type of cost, i.e., proactive investments in resilience constructs, can be sub-divided into network and company-level perspectives. From a network perspective, studies are mostly concerned with SC network design (Aldrighetti, Battini, Ivanov, et al., 2021; Bottani & Montanari, 2010). For example, Cardoso et al. (2015) offer a multi-objective programming approach coupled with a quasi-total cost approach considering initial investment into processes, process expansion investments, and storage capacity extension investments for multiple nodes in an SC. Furthermore, another study within this domain investigates facility location problems for measuring the additional cost of redundant capacities across the SC (H. Fan et al., 2018). From a company-level perspective, Govindan et al. (2020) measure the additional cost (i.e., product cost, logistics cost, and quantity discount) for “resilient” suppliers. Another study focuses on supplier configuration and respective resilience surplus costs (Fahimnia et al., 2018). Schütz and Tomasgard (2011) introduce the construct of flexibility in terms of volume, delivery, and operational decision making for SC planning under uncertain demand in the Norwegian meat industry with the help of a stochastic programming model, keeping in mind production cost, transportation cost, and inventory cost (Schütz & Tomasgard, 2011). A study from the airline industry describes resilience costs as the difference between delay costs with and without proactive measures in place (Cook et al., 2016).

Most of the resilience cost literature reviewed focuses on the additional expenses of individual practices and measures; their results are rarely applicable to multiple practices. Taking the breadth of SSRES practices into consideration, the current body of research lacks a holistic approach to measuring the cost of proactive, concurrent, and reactive SSRES practices. Against this backdrop, PSM offers a plethora of established costing methods for practice cost calculation, however, no study in resilience cost literature could be identified that makes use of this knowledge. These costing methods are most often used in the context of decision-making, especially in MCs. These decisions include supplier selections, supplier evaluations, make-or-buy decisions, or general investment decisions for the adoptions of practices (Degraeve & Roodhooft, 1999; Dogan & Aydin, 2011; Ellram & Siferd, 1993; Fill & Visser, 2000; Kumar & Nagpal, 2011; Sharma, 2016). A set of the most prominent methods, including strengths, weaknesses, and suitability for this research, will be introduced in the following (see Table 6).

Traditional costing is conducted under the premise that information about procurement goods can be found in the cost structure of a product (Schönsleben, 2007). A simple calculation methodology, it is solely usable in product costing applications and does not exhibit the required flexibility for usage in SSRES practices. *Activity-based costing (ABC)* is an approach developed by Cooper and Kaplan (1988) for "the costing and monitoring of activities, which involves tracing resource consumption and costing final outputs. Resources are assigned to activities and activities to cost objects. The latter use cost drivers to attach activity costs to outputs" (CIMA, 2013). While traditional absorption costing focuses on volume-related cost drivers (e.g., labor hours), ABC focuses on transactional cost drivers (e.g., number of purchase orders) that incur costs, facilitating the allocation of overhead toward specific products, projects, or practices (Cooper, 1987). Since an SSRES practice can be considered a set of activities (Bromiley & Rau, 2014), ABC is a strong fit and could aid in tracking costs incurred and re-allocating these to individual practices. *Life cycle costing (LCC)* "seeks to optimize the cost of acquiring, owning, and operating physical assets over their useful lives by attempting to identify and quantify all the significant costs involved in that life, using the present value technique" (Woodward, 1997, p. 336). While this technique entails a transparent evaluation of costs, it can reach its limits, as it requires future cost predictions and can become quite complex (Korpi & Ala-Risku, 2008). In the context of SSRES practices, life cycle costing is restricted to asset-based practices such as inventory-related practices or the monetary aspect of supplier selection.

**Table 6.** Established costing methods in PSM

| Method | Cost drivers | Strengths | Weaknesses | Suitability |
|---|---|---|---|---|
| **Traditional costing** (Schönsleben, 2007) | Cost structure of a product | • Simplicity | • Only usable in product costing applications<br>• Low integration power with the practice definition<br>• Mainly limited to physical assets | Weak |
| **Activity-based costing** (Cooper & Kaplan, 1987) | Fixed costs in individual activities allocated to different resource pools | • High accuracy<br>• Transparency of cost calculations<br>• Broader focus for measuring practice costs<br>• High integration power with the practice definition | • High complexity<br>• High effort to acquire relevant data | **Strong** |
| **Life cycle costing** (APICS, 2008) | Phases of a product life cycle: development, production, service, usage, and disposal | • Transparent evaluation of costs | • High complexity<br>• Difficult to predict future costs<br>• Mainly limited to physical assets | Weak |
| **Supply chain costing** (Slagmulder, 2002; Wagner, 2008) | Cost determination along the entire SC (from raw material to end customer) | • Detailed cost breakdown per SC node<br>• High accuracy | • Low transparency<br>• High complexity, especially for small companies<br>• Requires data collection and sharing from suppliers | Moderate |
| **Total cost of ownership** (Ellram & Siferd, 1993) | Unit-related additional costs of a procurement good or activity, which may include the former as elements | • High flexibility<br>• High accuracy<br>• High controllability | • High complexity<br>• Moderate integration power with the practice definition | Moderate |

*Supply chain costing* considers activities and expenses upstream and downstream in the SC, as well as their interdependencies (Wagner, 2008). While this methodology allows full SC transparency, it reaches its limits in terms of practical feasibility, especially for smaller companies, as supply chain costing requires that additional actors provide information about incurred cost (Lalonde & Pohlen, 1996; Slagmulder, 2002). Therefore, supply chain costing is only moderately suitable for costing SSRES practices. Finally, *Total Cost of Ownership (TCO)* is a type of calculation designed to help a buying company evaluate direct and indirect costs and benefits of a product or service to be purchased over its entire life cycle (Degraeve et al., 2005; Ellram, 1993; Ellram & Siferd, 1998; Wagner, 2008; Wouters et al., 2005). While TCO has been adopted increasingly in MCs for supplier comparison purposes, its uses have extended to project and practice cost calculations (Hurkens et al., 2006; Smytka & Clemens, 1993). However, due to this model's high complexity and difficulty of integration with the aforementioned practice definition, it has only a moderate fit for costing SSRES practices. Overall, ABC is viewed as the most suitable costing methods for approaching SSRES practices. To the knowledge of the author, currently no research exists combining these two topics.

## 3.4 Research gaps and research questions on supply-side resilience operationalization for manufacturing companies

The literature reviews in Sections 3.1 to 3.3 enable the identification of research gaps and resulting research questions in the context of the dissertation topic. While the research gaps are addressed with a set of research questions, respectively, they do not build on each other, but rather provide components for reaching the overall research objective ($RO_0$).

**Research gaps and research questions for conceptualizing supply-side resilience for MCs**

An analysis of literature regarding the conceptualization of supply-side resilience for MCs reveals the following gaps:

- *PSM-specific research on resilience*: While the research on SC resilience has advanced in the past decades, its concrete application to the role of PSM is still in its infancy. While the concept of SSRES has been explicitly introduced by two studies using DCV as theoretical underpinning, potential for expanding this research exists.
- *Consistence of abstraction levels for SSRES practices*: The literature introduces a plethora of higher-order theoretical constructs to describe resilience. However, both SC resilience and SSRES studies are inconsistent when using the term "practice", especially in the manufacturing context. A synthesis of this fragmented literature could be of advantage to existing resilience literature.

- *Linking of lower-order SSRES constructs to higher-order SSRES constructs*: While some research links higher-order constructs explaining resilience (i.e., strategies, capabilities, elements) to each other, connection of these to lower-order constructs such as practices and activities is sparse. A refinement and expansion through conceptualization could enrich the scientific debate.
- *Contingency variables that influence the adoption and success of SSRES practices*: The context variables associated with the adoption of practices or practice combinations have not yet been investigated in detail. A detailed examination may aid in identifying both the internal and external contingency variables for SSRES adoption and their role in practice prioritization.

From the research gaps, the first three research sub-questions ($RQ1_a$, $RQ1_b$, and $RQ1_c$) can be formulated to address shortcomings in the current literature. While the elements and capabilities of SC resilience in MCs are quite well understood, both application of the concept to PSM and the concretization of the concept down to organizational practices are yet to be conducted. PBV (Bromiley & Rau, 2016) serves as the theoretical underpinning of these investigations and helps structure the constructs from a strategical to an operational level and identify their relationships as a foundation for subsequent studies. Furthermore, a systematic identification of internal and external contingency variables influencing the effectiveness of SSRES practices for MCs could advance the knowledge frontier. As an additional theoretical lens, contingency theory (CT) could be applied to structure the type and influence of these variables. Therefore, the first three research questions can be formulated as follows:

> $RQ1_a$: How can SSRES be conceptualized?
>
> $RQ1_b$: What are the SSRES practices of MCs?
>
> $RQ1_c$: What are the contingency variables relevant for the adoption of SSRES practices in MCs?

**Research gaps and research questions for measuring the effectiveness of supply-side resilience for MCs**

The literature on effectiveness measurement of SSRES reveals the following research gaps:

- *Matching KPIs to SSRES practices*: Many KPIs based on both financial and non-financial metrics have been developed and applied in resilience literature to measure the effectiveness of specific practices. While KPIs have often been identified mainly for one specific case and one specific practice, an investigation of which KPIs could be used in the context of which managerial practice has not yet been conducted. A comprehensive overview of KPIs as proxy indicators of SSRES practices could provide more clarity in the literature and could aid in the derivation of resilience MOEs.
- *Effectiveness measurement methods of SSRES practices*: Given these KPIs, the measurement of effectiveness still remains largely unclear. Oftentimes these studies are completed with the help of complex disruption simulation models supported by many assumptions, revealing a blind spot for practitioner-friendly methods to measure the effectiveness across different practices with low data availability.

The research gaps help determine a second pair of research questions ($RQ2_a$ and $RQ2_b$), which address the effectiveness measurement of SSRES practices implemented at MCs. PBV will act as the theoretical foundation for understanding SSRES. Consequently, the following two research questions will be answered in this dissertation:

> $RQ2_a$: What KPIs for measuring the effectiveness of SSRES practices exist?
>
> $RQ2_b$: Given suitable KPIs, how can the effectiveness of SSRES practices be measured by MCs?

**Research gaps and research questions for costing supply-side resilience for MCs**

The literature review concerning the costing of supply-side resilience at MCs reveals the following gaps:

- *Integration of activity cost into resilience considerations*: Resilience cost literature entails in-depth case studies with different penalty scores and cost types to measure the cost of measures that increase resilience. So far, no study could be identified which takes an activity-based costing approach to identify the different cost drivers and allocation of cost into resource pools. Such studies could advance knowledge on managing SSRES.

- *Cost measurement of SSRES practice portfolios*: Most resilience cost models focus on single practices and single companies in extremely specific internal and external settings. A broad, integrative view incorporating a portfolio of adopted SSRES practices in different manufacturing company settings could enrich resilience costing literature.

The last set of research gaps call for research questions concerned with the monetary evaluation of SSRES practices. Due to the fragmentation of the literature on resilience costs, a holistic view on SSRES practice cost with different cost elements is still needed. Complementary to the first two sets of research questions, a further breakdown of practices into activities could lay the foundation for the use of an activity-based costing approach could be supported by PBV. Consequently, the following two research questions ($RQ3_a$ and $RQ3_b$) guide the investigations:

*$RQ3_a$*: What cost elements are associated with SSRES practices for MCs?

*$RQ3_b$*: How could the setup, maintenance, and usage of SSRES practices be costed for MCs?

The fragmentation of literature on SSRES practice effectiveness and cost foreshadows the fragmentation of respective cost-effectiveness literature. Studies dealing with cost-effectiveness are mainly quantitative in nature, and thus inherently follow a positivist research paradigm with an economic rationale (Ryan, 2018). The rational choice theory (RCT) acts as a theoretical guideline to the overall investigations of this dissertation (Goode, 1997; Scott, 2000), as it provides the rational logic of decision-making that is required for the operationalization of SSRES in terms of cost and effectiveness. An investigation of SSRES at MCs in terms of conceptualization, effectiveness measurement, and costing could close specific gaps in resilience research and identify the relevance of resilience for PSM. If a method to both measure the effectiveness and the cost holistically for specific resilience practice constellations is developed, a CEA method resulting in practice recommendations could be developed for practitioners. This could help them to (1) receive insight on their current state of SSRES in terms of expenditure and effectiveness, (2) identify those practices that can be classified as "low-hanging fruit", and (3) derive implications for their resilience strategy. Consequently, this research is a steppingstone toward resilience management.

# 4 Theoretical positioning of the research on supply-side resilience operationalization for manufacturing companies

This chapter is dedicated to the theoretical underpinnings of this dissertation. While Section 4.1 provides an overview of the general research philosophy and approach, Section 4.2 describes the procedure for selecting the theories in detail and provides relevant theoretical perspectives used in research on SSRES operationalization. Sections 4.3 through 4.5 describe the three theories selected for this study in detail: practice-based view, contingency theory, and rational decision theory. Finally, the application of these theories within the scope of the dissertation is illuminated in Section 4.6.

## 4.1 Research paradigm and interpretation

The theory selection and research settings used to approach the research questions are significantly influenced by the author's paradigm choice. In general, this dissertation follows a positivist research paradigm, which aims to examine regularities and relationships in data that lead to generalizations (Gioia & Pitre, 1990). Implicitly, the generated theory "carries an […] orientation toward a managerial perspective" (Gioia & Pitre, 1990). Hypotheses within this paradigm are usually derived by the selection of specific variables as causes of an effect, either extending existing theory or filling a knowledge gap. Within this paradigm, the analyses are mostly quantitative, and results aim to confirm the proposed hypothesis. Nevertheless, the author is convinced of the benefit of triangulating quantitative analysis through qualitative data (Jick, 1979). While there are observable and measurable aspects of this research (e.g., the activity cost of SSRES practices), it also contains constructivist elements that are framed by the human mind (e.g., flexibility as an element of SSRES) and equally call for a qualitative research approach (Schwandt, 2000). Thus, the dissertation topic merits a mixed methods approach. Overall, the positivist research paradigm and the phenomenological interpretation of the unit of analysis provide the basis for the subsequent theory selection.

## 4.2 Theory selection procedure

Neither SCRM nor PSM research has yet developed a robust and rich theoretical base. Less than half of studies in the PSM field are theoretically grounded, and only 11% make use of external grand theories (Chicksand et al., 2012; Harland et al., 2006; Spina et al., 2016). Unlike in SCM research, the SCRM and PSM research fields have not yet developed internal theories. The deployment of external theories from broader areas of management, economics, and social sciences, aid the field in achieving higher maturity and increase the potential for own theory generation (Spina et al., 2016). There are several identifiable theory categories:

*Competitive theories* focus on how the individual firm strives to develop a competitive advantage in the market (Barney, 1991; Defee et al., 2010). The resource-based view of the firm is applied in the context of adopting resilience practices due to high imitation difficulty or cost intensity (Brusset & Teller, 2017). Additionally, the knowledge-based view of the firm helps understand the knowledge management processes for bolstering resilience (Massingham, 2010). The dynamic capabilities view can provide an underpinning for conceptualizing resilience (Ponomarov & Holcomb, 2009). Contingency theory aids in explaining the moderating variables on both practice effectiveness and cost (Donaldson, 2001).

*Decision theories* are concerned with providing a theoretical lens to aid decision-makers faced with a set of choices and consequences. Rational decision theory provides a theoretical lens when considering the cost-benefit analysis of making an investment into one or multiple resilience practices. While other approaches exist within this group of theories, such as auction and negotiation theory, they play a secondary role in this research.

*Microeconomic theories* are mostly applied in a firm-individual setting. These theories find wide application in studies within PSM and SCRM, in which cost-focused purchasing decisions such as make-or-buy are made. In this context, transaction cost theory may provide insight about the costs incurred and decisions based on incurred costs (Goode, 1997; Williamson, 1973).

For the appropriate theory selection, a set of requirements must be formulated. Based on the insights from Sections 2 and 3, applicable theories for this dissertation must fulfill the following *specific criteria*:

- Potential for the conceptualization of SSRES and integration of its associated practices and activities (Study A, B, and C)
- Provision of insight on the impact of contextual variables, both internal and external, on the adoption of SSRES practices (Study A)

- Acknowledgement of the economic nature of the decision to adopt a set of SSRES practices

Since no one theory can be expected to meet all the above criteria, it must also be possible to combine suitable theories with other theories. This idea provides a first indication of the theoretically eclectic nature of this dissertation. Stölzle (1999) identifies four types of *generic criteria* for organizing theory selection, in addition to the requirements stated above:

- *Theoretical attractiveness*: This category necessitates the existence of a research paradigm as well as an orientation toward critical rationalism. While the former considers the problem-solving power of a theory, its generalizability, and its precision grade, the latter considers a theory's explanatory performance and its potential to generate hypotheses.
- *Design orientation*: From a content-related perspective, this criterion entails efficiency criteria, design variables, and determinants. From a formal perspective, it refers to the existence of informativeness, empirical relevance, and application potential of the theory. In this context, design orientation requirements are fulfilled as soon as they provide insights into the operationalization of SSRES.
- *Integration power*: The requirements for integration power of a theory include its learning and systematization potential, as well as the potential to connect the theory with one or more theory sets. Applying this criterion to this dissertation, a theory fulfills this criterion in the context of this dissertation if it can contribute to the operationalization of SSRES in combination with other theories.
- *Adaptability*: The final criterion refers to the theory's overall suitability to the research context as well as its applicability to the research topic. Additionally, the criterion includes the consideration of special implications for the research topic.

The following theories are those most frequently used in the broader context of this research, providing a preliminary hypothesis of suitability for SSRES operationalization:

- Transaction cost theory
- Resource-based view
- Practice-based view

- Knowledge-based view
- Contingency theory
- Resource dependency theory
- Dynamic capabilities view
- Rational decision theory

All eight theories are summarized and tested against the specific requirements context of SSRES operationalization.

- *Transaction cost theory (TCT)*: TCT aims to predict which governance form will be used for which activity in an organization depending on transaction costs. More specifically, Williamson (1973) viewed transactions as transfers of goods or services, whose costs can be sub-divided into three categories: search and information costs, bargaining costs, and policing and enforcement costs (Williamson, 1973). TCT is often used in the context of make-or-buy decisions, considering the specificity of the product (Grover & Malhotra, 2003). Relating to the current research, TCT could aid in shedding light on SSRES practices such as nearshoring versus offshoring of MCs (Ellram et al., 2008; Ketokivi & Mahoney, 2020; McIvor, 2009; Wever et al., 2012). Therefore, this theory will be investigated in more detail.
- *Resource-based view (RBV)*: RBV provides insight into how companies can achieve a sustainable competitive advantage by being able to absorb and apply resources that are rare, non-imitable, valuable, and non-substitutable (Barney, 1991). RBV has been extensively used in the analysis of SC activities, operational strategies and effective use of process capabilities, and product-service innovations (Hitt et al., 2016; Safari & Saleh, 2020). As resilience literature is often concerned with achieving a competitive advantage during or after disruptions through the deployment of resources (Brusset & Teller, 2017; Cheng & Lu, 2017), RBV is considered for deeper analysis.
- *Practice-based view (PBV)*: PBV builds on the critique of RBV, by assuming that performance can be explained with a combination of imitable practices (Bromiley & Rau, 2014, 2016a, 2016b). While adopting some practices may negatively affect the company, PBV purports that the combination of the proper techniques, coupled with a deep understanding of their respective implications, can

explain a company’s performance in terms of profitability (Bromiley & Rau, 2016). As the theory may provide systematic insights into how SSRES practices are linked to a company’s performance (Ketokivi & Schroeder, 2004), it will be studied in detail in the next step.

- *Knowledge-based view (KBV)*: KBV offers a rationale that views knowledge as the most strategically significant resource of the company (Grant, 1996). The authors differentiate between explicit and tacit knowledge that can explain a competitive advantage. While explicit knowledge describes the generalized knowledge easily expressed and identified within the organization’s routines, records, and information system, tacit knowledge describes the company-specific knowledge that is difficult to transmit or encapsulate (Andreu et al., 2008; Curado & Bontis, 2006). As knowledge management is an essential element of SSRES both pre-disruption and post-disruption (see Section 3.1), KBV could offer insights toward the breakdown of these elements and their contribution to resilience.
- *Contingency theory (CT)*: CT posits that organizational effectiveness results from fitting company properties to contingencies, including the environment, organizational size, and organizational strategy (Donaldson, 2001). It demands that companies adapt themselves to new levels of contingencies over time in order to maintain their performance (Tate et al., 2022). While applied in risk management (Mikes & Kaplan, 2013), it offers potential to provide insight on the impact of contextual variables, both internal and external, on the adoption of SSRES practices, and thus on the operationalization of SSRES. Hence, it will be studied in further detail.
- *Resource dependency theory (RDT)*: RDT aids in explaining how a company’s behavior is affected by the external resources it possesses (Pfeffer & Salancik, 1978). RDT has considerable relevance in PSM, as it is dedicated to procuring external resources affecting organizational structure, production strategies, and personnel choice. For example, the dependency on resources like suppliers should be inversely proportional to the criticality of the procurement object in question (Nascimento et al., 2021). However, this theory is mainly focused on deriving implications for the strategic management of a company and does not

focus on practices themselves. Therefore, this theory will not be elaborated in the next step.

- *Dynamic capabilities view (DCV)*: The concept of dynamic capabilities was born from the supplementation of adaptation power to RBV to cover the requirements of a rapidly changing environment (Helfat & Peteraf, 2003; Teece et al., 1997). This theoretical lens assumes that an organization's possession of resources is a necessary but not sufficient condition for competitive advantage (Eisenhardt & Martin, 2000). These resources should be integrated, built, and reconfigured dynamically, responding to environmental change, and creating new value (Spina et al., 2016). DCV is extensively used in resilience literature to define the concept as the capability to resist and recover from shocks or disasters (Luthar & Cicchetti, 2000). While Pereira et al. (2020) and Dabhilkar et al. (2016) use DCV to structure SSRES, it requires the observation of the same unit of analysis at different points in time. As it is used in both studies explicitly conceptualizing SSRES, it is suited for further analysis.
- *Rational choice theory (RCT)*: RCT lies at the center of microeconomics (Scott, 2000). RCT posits that companies must anticipate the outcomes of different courses of action and select the most preferential option. A preference should be determined by maximizing the difference between the threat of punishment or the promise of reward (Goode, 1997; Heath, 1976). Furthermore, past experiences where an actor has experienced punishment may influence the decision (Tversky & Kahneman, 1981). In the context of the research topic, RCT could aid the buyer in conducting CEAs to decide future courses of actions. Therefore, this theory will be investigated in more detail in the next step.

Based on the initial filtering of suitability according to the specific criteria, seven out of eight theories can be viewed as applicable to the research context. In the following, the theories are tested against the generic requirements as formulated by Stölzle (1999): theoretical attractiveness, design orientation, and integration power. The full overview is provided in Table 7.

**Table 7.** Theory evaluation of the generic criteria according to Stölzle (1999)

| Theory | Theoretical attractiveness | Design orientation | Integration power | Applicability |
|---|---|---|---|---|
| **Transaction cost theory (TCT)** | Extensively applied in PSM and SCRM, aiding in characterizing buyer-supplier relationships and decisions such as outsourcing (e.g., Ellram et al., 2008; Wever et al. 2012) | Provides a theoretical foundation for arguing specific make-or-buy decisions from the focal company perspective (Grover & Malhotra, 2003), challenging to cover other practices | Allows for integration with RBV (McIvor, 2009), CT (Kros et al., 2019), and RCT (Ketokivi & Mahoney, 2020) | ◐ Medium |
| | L H | L H | L H | |
| **Resource-based view (RBV)** | Frequently applied in a resilience context, e.g., to examine which resources make some organizations more resilient than others (e.g., Cheng & Lu, 2017) | Explains solely how rare and non-imitable resources contribute to a competitive advantage (Barney, 1991), difficult to operationalize | Allows for integration with DCV (Peng et al., 2008), TCT (McIvor, 2009), and CT (Safari & Saleh, 2020) | ◐ Medium |
| | L H | L H | L H | |
| **Practice-based view (PBV)** | Young theory tested in risk management (e.g., Andersen, 2011), demonstrates potential for examining abstract concepts such as SSRES | Explains how imitable practices contribute to a company's performance (Bromiley & Rau, 2014), straightforward to operationalize | Allows for integration with CT (Ketokivi & Schroeder, 2004), RCT (Bromiley & Rau, 2016b) | ◕ High |
| | L H | L H | L H | |
| **Knowledge-based view (KBV)** | Extensively used in risk management, e.g., for managing knowledge during risk monitoring for disturbance anticipation (e.g., Blome et al., 2014) | Explains how knowledge and experience contributes to competitive advantage (Grant, 2006), challenging to operationalize | Allows for integration with CT (Blome et al., 2014) and DCV (Zheng et al., 2011) | ◐ Medium |
| | L H | L H | L H | |

| Theory | Theoretical attractiveness | Design orientation | Integration power | Applicability |
|---|---|---|---|---|
| **Contingency theory (CT)** | Extensively applied in risk management for describing different context variables influencing handling risks (e.g., Mikes & Kaplan, 2013) | Provides explanations for company performance adopting SSRES practices (Donaldson, 2001), contingency variables allow for structuring of moderating variables | Allows for integration with RBV (Safari & Saleh, 2020), KBV (Blome et al., 2014), RCT (Goode, 1997), and TCT (Kros et al., 2019) | High |
| | L H | L H | L H | |
| **Dynamic capabilities view (DCV)** | Extensively applied to theoretically underpin the concept of resilience in SCs (e.g., Tate, 2022) | Provides explanations on SSRES capabilities, but requires temporally distributed data before, during, and after disruptions (Cyfert et al., 2021) | Allows for integration with RBV (Peng et al., 2008) and KBV (Zheng et al., 2011) | Medium |
| | L H | L H | L H | |
| **Rational choice theory (RCT)** | Extensively applied to the allocation of resources for maximizing the effectiveness while minimizing the cost (Edwards, 1954) | Provides assumptions and structures for economic decisions for practice adoption; provides guidance for operationalization (Tversky & Kahneman, 1981) | Allows for integration with TCT (Ketokivi & Mahoney, 2020), CT (Goode, 1997), PBV (Bromiley & Rau, 2016b), and most other competitive theories | High |
| | L H | L H | L H | |

PBV, CT, and RCT are the theories considered for this study. Not only do they all match Stölzle's (1999) theory selection criteria, but they also fit together in the specific study context. Sections 4.3 to 4.5 go through the three chosen theories in greater detail, assign them to the research questions, and discuss their contributions to the dissertation. Section 4.6 displays the research framework, which summarizes and connects the various theoretical perspectives.

## 4.3 Outline of practice-based view

Bromiley & Rau (2014) propose PBV as an antithesis to RBV. While the Resource-Based View (RBV) attempts to explain a company's sustainable competitive advantage from company resources that are valuable, rare, hard to imitate or duplicate, and hard to substitute, PBV assumes that performance discrepancies can be explained by a combination of imitable practices (Bromiley & Rau, 2014). Companies can thus be seen as bundles of practices, which are defined as a set of activities, routines, and material arrangements (Russo-Spena & Mele, 2012; Schatzki, 2016; Schatzki et al., 2005). The dependent variable is performance, rather than RBV's sustained competitive advantage.[20] PBV's extended model comes with optional explanatory variables, which help explain the performance implications of specific practices (Bromiley & Rau, 2016a). PBV contributes to the present dissertation in three different ways.

First, PBV's extended model aligns well with the dissertation's view of SSRES and its objective of operationalization, as SSRES can be seen as a combination of practices influencing a hierarchy of intermediary explanatory variables, namely higher-order constructs (see Section 3.1) ($RQ1_a$). By attempting to understand the average effect of practices on organizational performance, PBV takes a broader view on many different constructs at the cost of depth and detail. The broad view helps in identifying many different practices ($RQ1_b$), which might be relevant to a buying organization.

Second, Bromiley & Rau (2014) comment on the effect of how a practice is implemented: "Firms have developed a plethora of variations in the details of executive compensation contracts and behaviors; these variations may cause the same practices to have different effects on performance across firms" (Bromiley & Rau, 2014, p. 1251). While the authors interpret performance as profitability, multiple non-financial metrics "act as the leading indicators for the financial performance" (Nudurupati et al., 2011, p. 284) ($RQ2_a$). Tying together the KPIs and SSRES practices aids in measuring the "effects on performance" and access the constructs via PBV ($RQ2_b$). Finally, Bromiley & Rau (2016) comment that moderating variables that explain the context of the practice should be considered in every PBV study. The stakeholders involved in the practice as well as the practice adoption configuration represent two reasonable candidates for moderators.

[20] This fits well to the context of the present dissertation, as no competitive analysis or comparison of the company's performance with a peer group is conducted. This is beyond the scope of the present research.

Third, PBV theoretically underpins the further breakdown of practices into activities as a foundation for responding to $RQ3_a$ and $RQ3_b$. The activity-based view sets the basis for data collection, analysis, and evaluation when aggregating cost elements and identifying different cost drivers for the setup, maintenance, and usage of SSRES practices.

## 4.4 Outline of contingency theory

Contingency theory originated in the 1960s and 1970s in order to solve problems of bureaucratic theory through organizational design (Donaldson, 2001; Sousa & Voss, 2008; Ven et al., 2013). At the core of the theory is the assumption that "there is no one best way to organize" (Galbraith, 1973). While the original focus of the theory lay on structural organization design (Donaldson, 2001), any proposition with a moderating variable can be considered a contingency theory argument (Ven et al., 2013). This means that that "the way a situation is managed, or a company is led is always contingent upon a specific case" (Gassmann et al., 2016), implying that one measure or decision that was successful in one environment might not be successful when transferred to a different domain.

Classical CT describes how contingency variables and organizational design, i.e., internal and external arrangements of work, influence organizational effectiveness. This relationship of constructs is valid under a set of assumptions: organizations as 'open rational systems'[21] and the bounded rationality of decision-makers[22]. SSRES is strongly context-driven and should be empirically derived through the organization's goals (Turkulainen & Ketokivi, 2013). CT can be thus viewed as a constrained optimization problem: at the organizational level, this entails the maximization of effectiveness through minimization of environmental demands and internal organization design (Ven et al., 2013).

Applied to this dissertation, CT specifically aids in structuring the configuration of SSRES practices and the identification of moderating variables on the practice adoption ($RQ1_c$). First, CT identifies contingency variables such as organizational size (Blau,

[21] CT sees organizations as 'open rational systems' (as opposed to close and/or natural systems) (W. R. Scott, 1998). While the open system view supports that organizations are self-maintaining due to the throughput of resources from the environment, the rational systems view assumes that organizations are instruments specifically designed and managed to reach specific goals (Tate et al., 2022).
[22] CT assumes bounded rationality in human behavior (March & Simon, 1958). This assumption describes how a rational decision maker will never find a globally optimal solution, but rather a locally optimal solution achieving the set targets.

1970; Pugh et al., 1969), environmental uncertainty (Lawrence & Lorsch, 1967), and market position (Pugh et al., 1969). While some variables are fixed and backed by hard data (i.e., organizational size), some are highly dependent on perception (i.e., environmental uncertainty). According to CT, the manifestations of the contingency variables have an influence on the choice of SSRES practices. For instance, an effective practice in one company and SC environment may not be effective in another.

## 4.5 Outline of rational decision theory

RCT suggests that an actor (company or individual) prioritizes the maximization of its/their own wealth and satisfaction in decision-making (Veblen, 1900). This view posits rational behavior of the actor in line with the homo economicus (Smith, 2015). While all actions are rational and made by considering costs and rewards, the reward of an action must outweigh the cost to be completed. RCT thereby assumes that decision-makers are in full control of their decisions. As soon as the reward falls below the incurred cost, the action will stop. Decision-makers will use disposable resources to optimize their benefit-cost ratio (BCR). Critics argue that decision-makers will in any case argue that they chose the option with the highest BCR (e.g., someone donating and losing money, but gaining in social prestige and thereby becoming more attractive to investments) (Goode, 1997).

Applied to the present research, RCT is an essential guideline for making economically viable decisions for investing in or divesting from SSRES practices that maximize benefit while minimizing cost. Noticeable in this context is the time dependence of rational choices. On one hand, investments in SSRES practices might incur costs in the short-term and therefore have a low BCR for a considerable amount of time. On the other hand, a disruption fundamentally changes the BCR, due to having practices in place to anticipate, respond, adapt, recover, and learn. As the present dissertation ultimately aims at the development of a method that can conduct CEA on SSRES practice portfolios, RCT acts as the encompassing theory.

## 4.6 Theoretical framework for research on the operationalization of supply-side resilience practices for manufacturing companies

Figure 11 depicts the theoretical framework of this dissertation, serving as guidance for the investigations by linking the research context and the applied theories. The framework is based on the managerial and theoretical relevance of SSRES operationalization by MCs presented in Chapter 1, the related fundamentals outlined in Chapter 2, the literature review of operationalization elements in Chapter 3, and the theories described in the current chapter. The research entails an eclectic approach by employing three different theoretical lenses (i.e., PBV, CT, and RCT). This is necessary in light of the discussed selection criteria, which could not be met by a single theoretical approach (see Section 4.2).

The investigations are embedded in RCT, as this theoretical lens serves to structure and guide this research. During the conceptualization phase, PBV is used to arrange the understanding of SSRES throughout multiple abstraction levels. Further embedded in PBV, CT is considered when investigating the contingency variables for the adoption of SSRES practices. PBV further guides the cost and effectiveness measurement, as it aids in further breaking down practices and identifying cost drivers. The synthesis of individual measurements leads to a holistic cost-effective analysis, equally embedded in PBV. Ultimately, the operationalization of SSRES culminates in a recommendation of which practices should be adopted and which not, given the internal and external circumstances. RCT plays a central role in guiding this recommendation according to the criteria identified during the former phases.

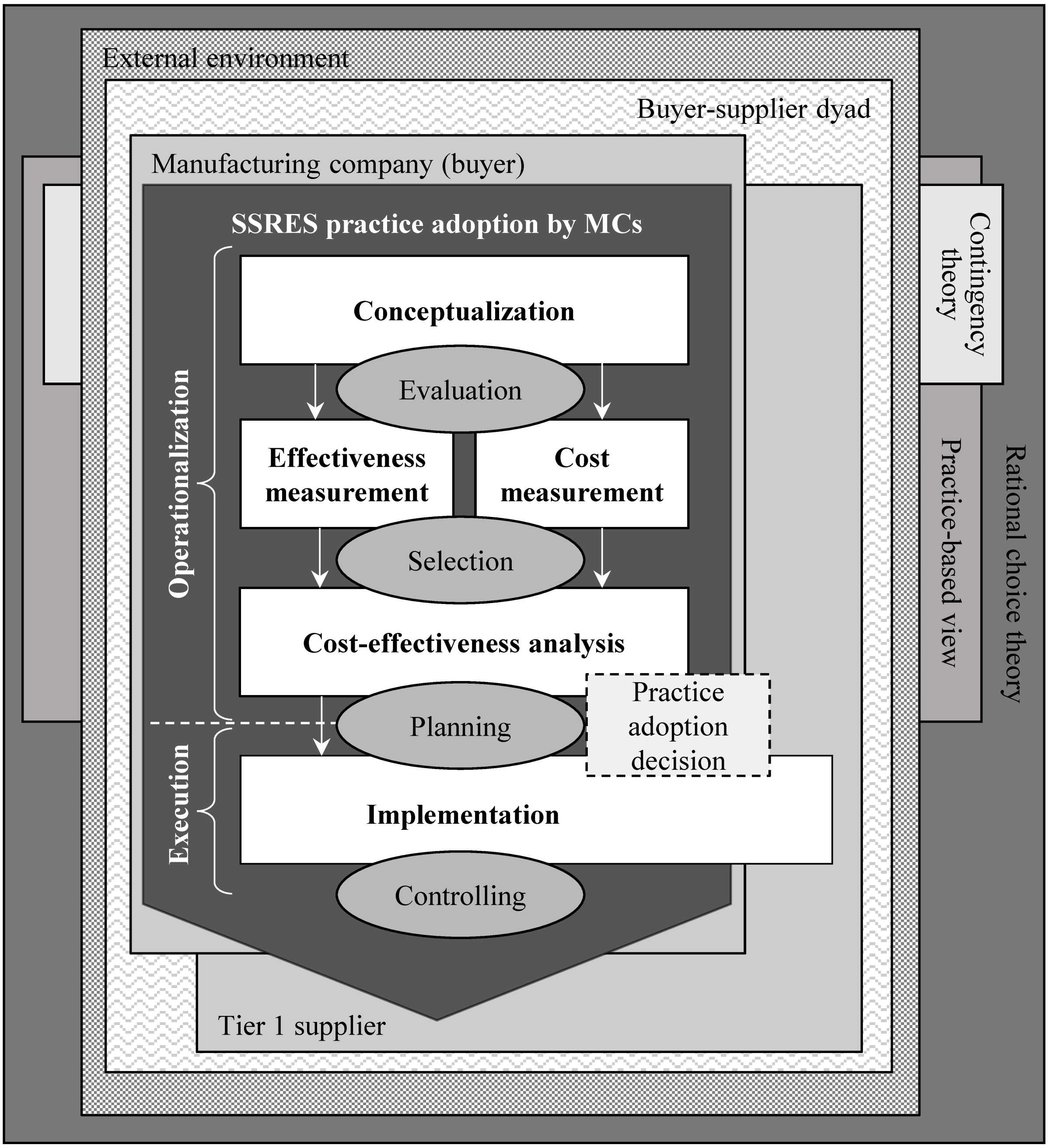


**Figure 11.** Theoretical framework of the dissertation

# 5 Studies on supply-side resilience operationalization for manufacturing companies

Chapter 5 presents an overview of the dissertation's research methodology as well as the findings of the individual studies. In Section 5.1, the studies are tied to each other and embedded into the theoretical framework from Section 4.6. Sections 5.2 to 5.4 describe the individual studies in terms of their objectives, research design, key findings, and contributions. Finally, Section 5.5 outlines the synthesis of the studies' results into a method for SSRES operationalization for MCs.

## 5.1 Research overview and methodology

Figure 12 illustrates the location of the studies within the theoretical framework. At its core is the overlay of SSRES practice adoption within a buyer-supplier dyad. Thereby, the SSRES practices serve as the *unit of analysis*. In all three studies, the *unit of observation* is the buying organization in MCs, as outlined in Section 1.4). All actors are surrounded by an external company environment characterized by environment-specific variables and disruption-specific variables. The conceptualization of SSRES (Study A), the effectiveness measurement of SSRES practices (Study B), the cost measurement of SSRES practices (Study C), and finally the integration and synthesis of the results is conducted from the perspective of the MC buyer. As the research is focused on SSRES operationalization, it excludes the collaborative aspects and incentivization mechanisms required with SC partners during execution and implementation of the practices, as this is beyond the scope of this dissertation. Instead, the three studies and the synthesis provide the necessary foundation for deciding whether to develop or explore further SSRES practices.

As each study puts an emphasis on different components of SSRES operationalization, this research is organized into four distinct research phases:

- *Research phase 1*: Development of an SSRES concept including practices for MCs
- *Research phase 2*: Development of an effectiveness measurement method for SSRES practices for MCs

- *Research phase 3*: Development of a cost measurement method for SSRES practices for MCs
- *Research phase 4*: Synthesis and integration of the results into a method to conduct CEA on SSRES practices at MCs

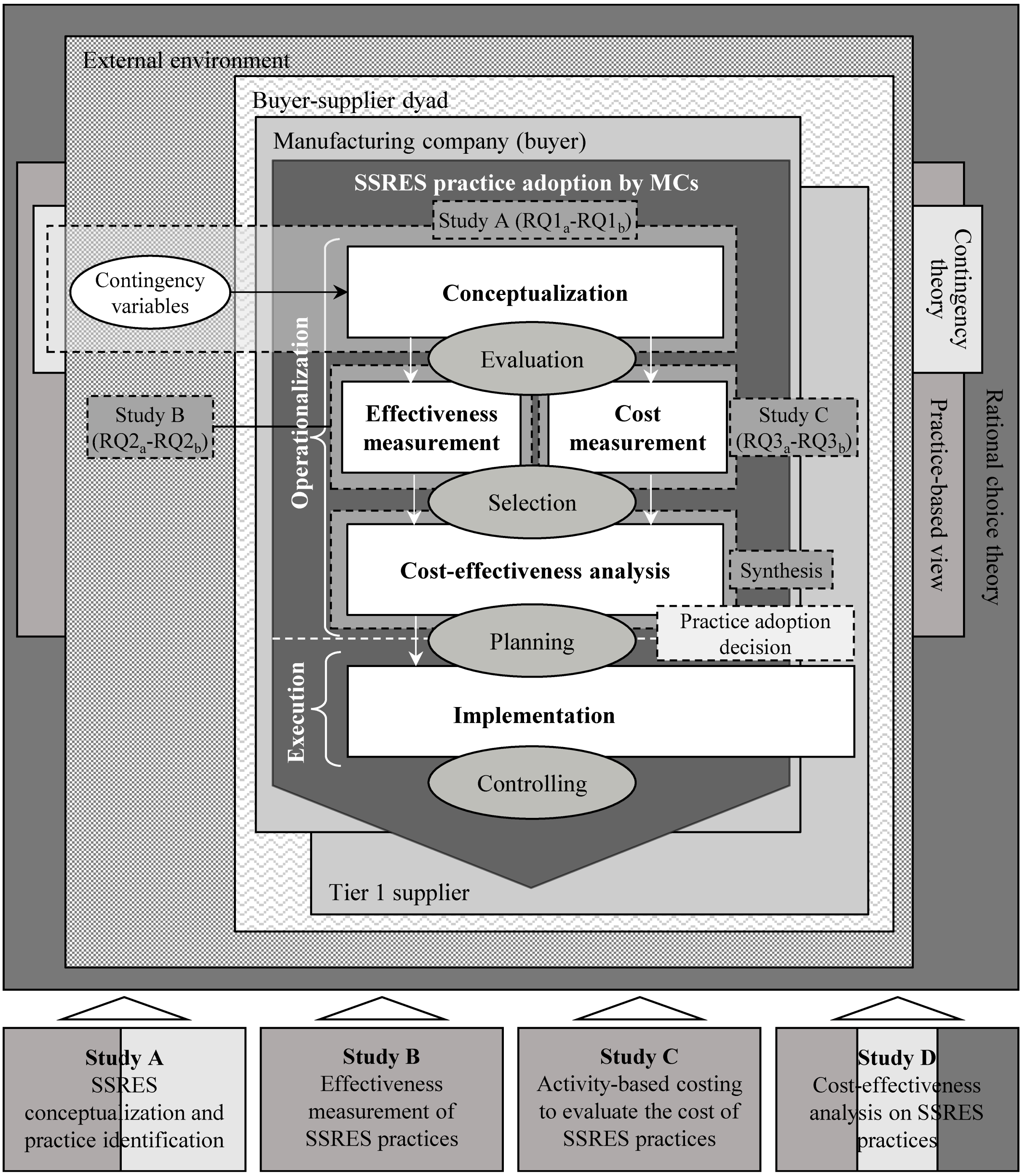


**Figure 12.** Location of the studies on the operationalization of SSRES practices

In order to meet the overarching research objective $RO_0$, the development of a method to operationalize SSRES at MCs, and to answer the seven posed research questions, one study has been carried out throughout each research phase. Study B and Study C both draw on the conceptualization of SSRES offered in Study A. The integration and synthesis of the individual studies is presented in the final research phase. The three studies each provide an essential contribution to creating the resulting method.

Study A, corresponding to research phase 1, examines the conceptualization of SSRES. It provides answers to $RQ1_a$ by developing a concept describing SSRES with the integration of higher order and lower order constructs. In response to $RQ1_b$, the study provides a catalog of SSRES practices tied to specific objectives and higher order constructs. Each practice can be adopted in a specific configuration. PBV provides structure for the constructs, as well as explanations for the influence of different practices on SSRES. Furthermore, the study is supported by CT, which helps in the extraction of both internal and external contingencies that influence the adoption of practices, answering $RQ1_c$.

Study B, corresponding to research phase 2, examines the KPIs used to measure the effectiveness of SSRES practices. It extracts and matches different types of KPIs to specific SSRES practices ($RQ2_a$). It further applies these findings in a case study, where the effectiveness of a practice – robust supplier selection criteria – is measured ($RQ2_b$). PBV serves as the theoretical underpinning, building on the conceptualization presented in Study A.

Study C, corresponding to research phase 3, investigates the monetary evaluation of SSRES practices through a breakdown of activities. Using a multiple case study setting, it provides answers to $RQ3_a$ by identifying cost elements belonging to each practice and determining resource pools. By the subdivision of practices into setup, maintenance, and usage activities, the aggregation of cost elements allows for statements regarding the expenditure on SSRES practices over specific periods of time ($RQ3_b$). PBV serves as the theoretical underpinning of the study and helps structure the breakdown of practices into activities.

The synthesis of the studies, corresponding to research phase 4, represents the culminating method of the dissertation by combining and extending the components from the previous studies. It builds on the conceptualization of SSRES from Study A, makes use of the effectiveness measurements and contingency variables in Study B, and applies the cost measurement method from Study C to address the overall research objective

$RO_0$. More specifically, this is done by the development of RESPIRE, a resilience practice recommendation system for MCs. As this is a combinatory study, the theoretical underpinning includes PBV, CT, and RCT. Table 8 presents an overview of the studies undertaken throughout this research.[23]

**Table 8.** Overview of the three studies and synthesis on SSRES operationalization for MCs

| | **Study A** | **Study B** | **Study C** | **Synthesis** |
|---|---|---|---|---|
| **Title** | Supply-side resilience: a practice-based view | Measuring the effectiveness of supply-side resilience practices | Determining the cost of resilience: an activity-based costing approach for buyers | RESPIRE: The resilience practice recommendation system |
| **Objective** | Conceptualizing supply-side resilience and identifying practice as well as their adoption configuration | Analyzing and matching KPIs to supply-side resilience practices to measure their effectiveness | Developing an activity-based costing method for evaluating SSRES practice expenditures | Developing a method to identify the current SSRES status and deriving practice recommendations |
| **Related research questions / research objective** | $RQ1_a$: How can SSRES be conceptualized?<br><br>$RQ1_b$: What are the SSRES practices of MCs?<br><br>$RQ1_c$: What are the contingency variables relevant for the adoption of SSRES practices in MCs? | $RQ2_a$: What KPIs for measuring the effectiveness of SSRES practices exist?<br><br>$RQ2_b$: Given suitable KPIs, how can the effectiveness of SSRES practices be measured by MCs? | $RQ3_a$: What cost elements are associated with SSRES practices for MCs?<br><br>$RQ3_b$: How could the setup, maintenance, and usage of SSRES practices be costed for MCs? | $RO_0$: An examination on how to operationalize supply-side resilience in terms of cost and effectiveness for MCs under certain circumstances. |
| **Methodology** | • Systematic literature review<br>• Multiple case study (general)<br>• 6 case studies (MCs) from 8 interviewees, risk-related data | • Systematic literature review<br>• Case study with MC including internal and external data and 2 interviewees | • Multiple case study (general)<br>• 5 case studies (MCs) from 10 interviewees, cost, and risk-related data | • Conceptual work and drawing on methodology from Studies A-C<br>• Case study (complementary) |
| **Applied theories** | • Practice-based view<br>• Contingency theory | • Practice-based view | • Practice-based view | • Practice-based view<br>• Contingency theory<br>• Rational choice theory |

[23] For a detailed outline of methodology choice, please consult the corresponding full papers in the Appendix.

The methods of the individual studies were chosen to appropriately answer the research questions. While general SC resilience is an established concept, procurement-specific literature is fragmented and reveals several blind spots. Therefore, a systematic literature review (SLR) coupled with a qualitative multiple case study method with a broad approach was chosen for the SSRES conceptualization in Study A. The effectiveness measurement (Study B) and cost measurement (Study C) of SSRES practices require both quantitative and qualitative data. Therefore, mixed methods case studies were used. For the synthesis of the results, conceptual work and a complementary case study were selected based on the methods and results of Studies A-C.

## 5.2 Study A: Supply-side resilience: A practice-based view

The following section provides a summary of Study A, including its research design as well as its findings and contributions.[24] Furthermore, its implications for addressing M1 are outlined.

**Research design of Study A**

Study A highlights the relevance of the conceptual understanding of SSRES for MCs. Decision-makers in procurement are aware that building resilience in their buying organization is essential, but do not always fully grasp the concept. While various studies identify specific higher-order SSRES constructs such as capabilities and strategies (Dabhilkar et al., 2016; Pereira et al., 2014, 2020), research is generally fragmented and lacks a connection of the concept to a lower-order, operational level. This study seeks to integrate and complement the literature by providing a conceptualization model that outlines and connects the different constructs of SSRES ($RQ1_a$). Acting as an interface with the upstream SC, decision-makers in procurement search for practices that positively influence the resilience of the upstream SC. A wide range of managerial practices to address general SC resilience exist, however, their relevance for decision-makers in procurement is not clear. Therefore, this research aims to follow a deductive research approach to identify PSM-relevant practices ($RQ1_b$). Finally, the adoption of SSRES practices differ widely between companies depending on internal and external contingencies. This study aims to identify these variables and embed them into the SSRES concept to give practitioners a custom view of their SSRES ($RQ1_c$).

[24] Section 5.2 largely cites the equivalent full paper in Appendix A.

The study follows a three-stage abductive research logic. While Stage 1 identifies SC resilience practices deductively through a literature review, Stage 2 transfers these practices into the setting of PSM through a survey. Finally, Stage 3 inductively investigates SSRES practices in detail in six cases with MCs. A funnel-like, explorative research setting was selected due to the lack of empirical research on this topic. A combination of qualitative and quantitative methods to study the SSRES constructs was chosen (Goldsby & Zinn, 2018).

In Stage 1, a literature review was conducted to collect SC resilience practices and provide categorization into the framework of PBV. A database search was conducted on Scopus and Web of Science for a period of 22 years (2000-2021). This period was chosen due to the first appearance of SC resilience literature in the mid-2000s (Pereira et al., 2014). The selection of the papers was made through search strings relating to SC resilience itself, PSM, and buyer-supplier dyads (Table 2). Papers were screened according to title and abstract. A more in-depth reading of the introduction and conclusion and a quality assessment were the final criteria for finding concrete resilience practices used, mentioned, and analyzed. A narrow interpretation of Bromiley & Rau's (2014) practice definition was taken to judge whether an object was a practice, i.e., the ability to break down the object into setup activities and recurring activities (e.g., alternative backup transportation method). In case the object was too abstract to break into concrete activities, the candidate in question was categorized as an objective (e.g., increase in transportation flexibility). After identifying the practices and their associated objectives, the objectives were assigned to the SC resilience elements as defined by A. Ali et al. (2017). Objectives were matched to elements through codes synonymous to the element, or the objective mentioned the element itself (e.g., the objective increase in transportation flexibility is allocated to the element flexibility).

In Stage 2, the objective was to determine the PSM relevance of the collected SC resilience practices. With PSM relevance, the extent to which the practice falls within the responsibility sphere of the buyer is implied. The current lack of robust, empirical research on SSRES practices led to use of a survey to explore the delimitation of SC resilience in the PSM setting. For this purpose, a small-scale survey with 62 buyers from Swiss and German MCs was conducted. While the rather small survey sample allows for limited generalization, it did serve the purpose of framing the issue (Goldsby & Zinn, 2018; van Hoek, 2021). The PSM relevance of each collected practice was evaluated on a Likert scale (from 1 = irrelevant to 5 = highly relevant). All practices with an average score below 3 were deemed irrelevant and excluded from further investigation. The survey format was online, and distribution took place via email.

In Stage 3, a series of semi-structured interviews with the respective CPOs of six selected MCs was conducted. While all companies are headquartered in Germany and Switzerland and can be allocated to the MEM (machine, electronics, and metals) industry, their products, supplier portfolios, and PSM processes and structures widely differ from each other. The objective of this stage was to determine (1) the SSRES practices currently adopted in the individual company, (2) their respective level and context of adoption, as well as (3) their respective ease of adoption and effectiveness of usage in their respective phases. For this purpose, a typology across three categories, i.e., adoption governance, adoption level, and evaluation, was used to categorize and judge the individual practices.

**Findings and contributions of Study A**

The contribution of this study is threefold: First, SC resilience practices are systematically collected and structured to derive operational activities from each practice. Through an SLR, the study has identified 135 practices and 88 subelements and assigned them to 13 SC resilience elements. Therefore, the current SC resilience literature is complemented as the practices mentioned represent concrete and well-defined activities. Second, the study further consolidates the concept of SSRES, a combination of those SC resilience practices highly relevant for PSM managers. It is determined through a survey with buyers and risk managers of MCs that around two-thirds of mentioned SC resilience practices are suitable for the PSM function, confirming the validity of PSM for securing resilience both within and outside the organization. A full catalog of SSRES practices is provided in the Appendix, Section A.8.1. Third, the status of SSRES practice adoption by Swiss MCs in the MEM industry with a high procurement volume relative to its revenue is analyzed. The study provides a practice adoption typology for each practice to limit the adoption context for practices. By evaluating the ease of adoption and the effectiveness with PBV as a theoretical underpinning, the study provides a conceptualization of SSRES for practitioners. The cases reveal some insights on the SSRES of MCs in the MEM industry yet pose some limitations for SSRES research. As all practices adopted in the companies are also mentioned in the literature, the study confirms the validity of the proposed SSRES practice catalog. The adoption typology aids practitioners in assessing the context of the practices and a cross-product or cross-supplier evaluation of their SSRES. The results generally support the view that SSRES is a practice-based concept, as the individual composition of the various practices influences company performance. Nonetheless, three main company contingency variables could be derived from the results, which influence the practice adoption and usage: (1) experience with disruptions, (2) company resources, and (3) market position.

Younger and therefore less experienced MCs struggle to devise and execute a systematic SSRES strategy. This is partly due to the lack of *experience with disruptions*. PBV must be thus seen as a cycle, as it provides a snapshot in time and does not consider the evolutionary aspect of SSRES initially, i.e., how practices are adopted and abandoned and in which context (Pereira et al., 2020). The capability to learn from experience or transferred knowledge about a disruption is crucial. Therefore, these findings can be partially underpinned by the knowledge-based view, which sees competitive advantage through experience (Grant, 1996).

Furthermore, MCs often struggle to adopt a balanced SSRES practice portfolio due to a lack of *resources*. Smaller MCs are more likely to adopt practices requiring minor change and disruption to the organization in terms of processes, structure, and culture (Bromiley & Rau, 2016). Those with more resources were able to adopt more practices, as the results demonstrated. For example, Company D was able to acquire "a little extra of everything" in terms of safety stock and backup suppliers (Risk manager, Company D). This implies that practices require resources, and some are not imitable for all companies. In this regard, PBV thus reaches its limits and should take into account the resources as a contingency variable to adopt practices. RBV could explain this variable as it detects the inimitability of resources as a source of competitive advantage (Kraaijenbrink et al., 2009). Regarding the comments of Brusset & Teller (2017) that company size has no influence on its resilience, this research tends to agree, however, company size is an indicator for the resources deployable to adopt SSRES practices. This research argues that SSRES has an effect on company size, which consequently has an effect on what type of practices are adopted, maintained, and used which ultimately bolster SSRES.

Finally, the more established MCs have more frequently adopted practices beyond company boundaries (AL-e). This may be mainly due to their strong *market position* to incentivize their suppliers to cooperate (Christopher & Peck, 2004; Pettit et al., 2010). Notwithstanding, their adoption ease is mostly perceived as low, as larger companies have more complexity and a higher number of processes (Melnyk et al., 2021). However, as mentioned before, larger MCs have the resources to adapt. This supports the market-based view, which sees market conditions as the decisive force for performance differences among companies (Caves & Porter, 1977).

Furthermore, external contingency variables regarding the environment and the type of disruption were identified.

Going hand in hand with the market position of the company, environmental variables such as *market competition* play an essential role in SSRES. Several authors argue that resilience has the ultimate goal of creating a sustainable competitive advantage (Ali et al., 2017), where the balance of profit erosion through practice investments and risk exposure through lean structures and processes must be found (Pettit et al., 2010, 2013). SSRES has an indirect influence on the market position, as it determines the performance of the focal company before, during, and after a disruption based on the expenditure and effectiveness of their practice portfolios. The market competition cannot be analyzed in this research due to lack of data and transparency into the competitive structure. This will be up to future research endeavors.

In general, two types of disruptions can be distinguished. While instantaneous disruptions describe sudden cycles of downturn and quick recovery caused by a single disturbance on a single supply chain tier, super disruptions describe the consequence of disturbance cascades across multiple supply chain tiers. The *disruption type* has an influence on the SSRES practices in terms of their effectiveness. Therefore, practitioners must adapt their practice portfolio according to their resilience time horizon.

Figure 13 shows the resulting framework complemented by the results of the company cases. The SSRES mainly influences the three aforementioned variables “experience”, “resources” and “market position” via a self-learning feedback loop. Thereby, SSRES has a direct influence on experience, while it only has an indirect influence on resources and market position. This circumstance results from the fact that more resources are available as a result of better overcoming disruptions than without the corresponding

SSRES. The market position is also strengthened by the fact that the company overcomes disruptions better than companies with poorer SSRES. We therefore offer a revised definition of SSRES: *It can be defined as the state of a focal company to deal with disruptive risks originating in the upstream supply chain and escalating downstream. This state is fed by a dynamic feedback loop primarily driven by a set of practices tied to specific objectives that enhance the capabilities of anticipating, adapting, and responding to as well as recovering and learning from the disruption occurring as a consequence of these risks. The adoption, maintenance, and usage of these practices are influenced by company resources, market position, and experience as well as disruption and environment-specific variables.*

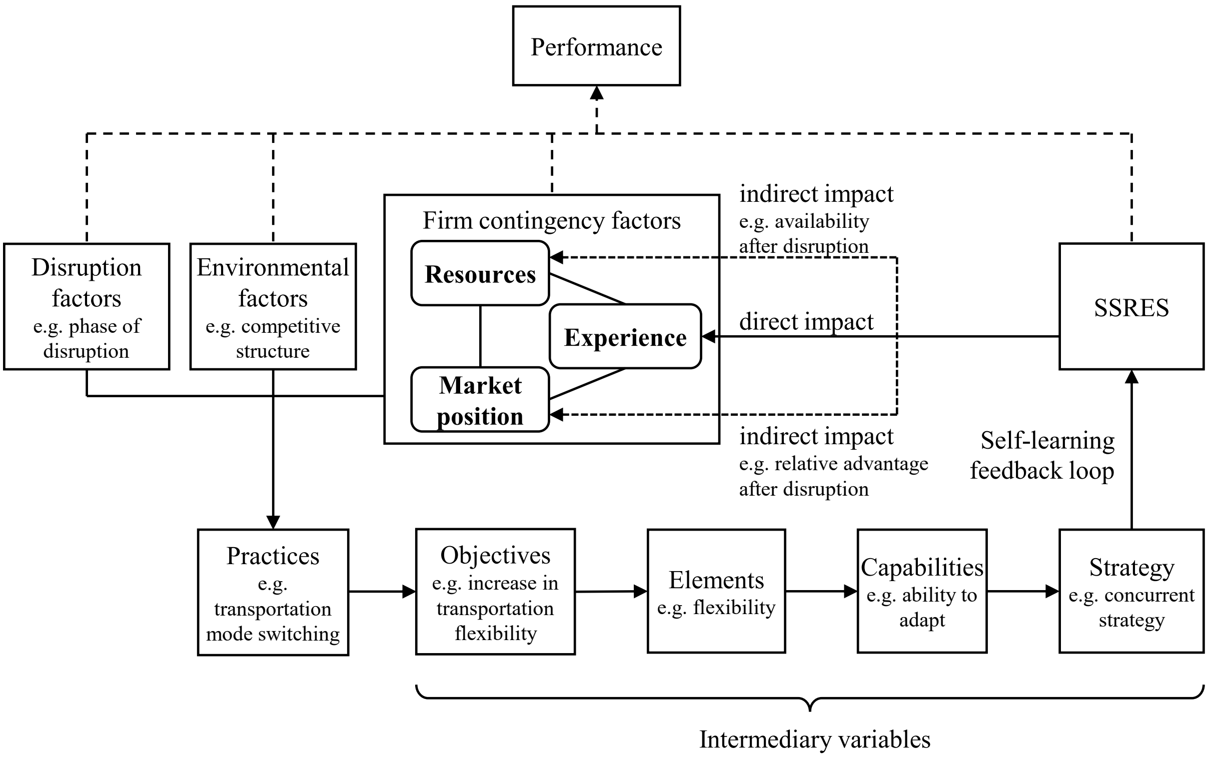


**Figure 13.** SSRES through the lens of PBV (adopted from Study A)

The conceptual model based on PBV reveals that resources as a company contingency play a key role in building and managing SSRES. While some of the practices adopted are imitable across companies of any size, others are not due to the limited investment capacity of smaller companies. As the resource in this case is investment capacity, which is imitable, RBV is not valid. However, KBV is partially valid because the experience extracted from internal and external knowledge can be highly influential in determining practices. Furthermore, the researcher's critique on the usage of DCV lies in its dynamic nature; as evaluated in the results, it is generally unclear how fast or steep a recovery would have been without a specific practice. For correct application of DCV, independent snapshots before and after the disruption would be necessary. While there is validity in the view that the practices and resulting capabilities dynamically adjust with every new disruption in the feedback loop, there are also challenges in the application of DCV due to the lack of data. Overall, PBV extended by components of resources and knowledge acts as a suitable theoretical underpinning.

The study helps practitioners grasp the concept of SSRES by integrating the strategical constructs with operational constructs. By compiling a comprehensive portfolio of SSRES practices and an adoption configuration typology, managers can identify and classify the practices adopted in their MCs on an operational level and identify gaps on a strategical level. By considering managerial and academic literature presenting different understandings of resilience, this study provides a rigorous foundation through systematic conceptualization, for subsequent application. The contingency variables derived can help managers understand the influence variables on their SSRES practice combination. The highlighted variables (resources, market position, and experience) should guide practitioners as to which practices should be prioritized. For example, only companies with a powerful market position can incentivize suppliers to adopt practices. While they are usually more difficult to adopt due to high coordination efforts, they can be highly effective. Practices are equally challenging to adopt when applied to product groups (due to their broadness) and product parts (due to their specificity). Finally, the experience with past disruptions has a decisive impact on how many and how broadly SSRES practices should be adopted.

## 5.3 Study B: Measuring the effectiveness of supply-side resilience practices

This section is devoted to summarizing the insights from Study B. Following the structure of the previous section, this summary includes outlining the research design, the findings and contributions, and the implications of the study for M2.[25]

[25] Section 5.3 largely cites the equivalent full paper in Appendix B.

**Research design of Study B**

Study B analyzes the role of KPIs in the effectiveness measurement of SSRES practices and applies it as a case study, from which the effectiveness of an exemplary SSRES practice is empirically derived. Many studies have attempted to measure resilience using proxy performance indicators. The breadth of this literature has led to its fragmentation and calls for the systematization and assignment of these KPIs to known SSRES practices. The methodology of this research is essentially subdivided into two stages. While the first stage includes an SLR to answer $RQ2_a$, the second stage is an application of the knowledge acquired in the first stage to a real-world example to answer $RQ2_b$.

Building on Karl et al.'s (2018) assignment of KPIs to SC resilience elements, the aim of this research is to descend to a further operational level that matches the identified KPIs with specific SSRES practices. Two academic databases, Scopus and Web of Science, were searched according to the interface of three constructs: SC resilience, procurement, and KPIs. Altogether, 11,765 documents were found for a defined search period of 21 years. Filtering and screening according to rigorous criteria (i.e., peer review, existence of empiricism, organizational vantage point) led to a final selection of 89 articles. The identified practice is matched with the catalog from Study A, and the KPI will be further investigated in terms of perspective (who measures) and target (who is measured). This will ultimately result in an assignment of KPIs to practices, which then acts as a foundation for the second stage of this research.

To address $RQ2_b$, this study applies the findings of the first stage to measure the effectiveness of a specific SSRES practice adopted in the MEM industry. The data for this case is provided from a key partner within a research consortium from the Swiss manufacturing industry. The case study uses a supervised machine learning approach divided in three steps. The first step consists of data collection and exploratory analysis of company-internal supplier data and complementary secondary data, aggregated to a feature set of independent variables. Based on the KPIs identified for this practice, a ternary supplier resilience metric is calculated, which constitutes the dependent variable. Following the data collection phase, the second subphase includes the development, training, and application of a multi-variable supervised machine learning model, with the aim of predicting the resilience of both current and new suppliers. The final step is dedicated to comparing the supplier prioritization of the model to the current subjective supplier evaluation. The implications of this prioritization, i.e., supplier selection, is then compared in a scenario analysis step utilizing the with/without principle.

**Findings and contributions of Study B**

Study B's contribution is two-fold: First, it provides an overview of the most frequently used KPIs in connection with SSRES practices. An SLR has identified 6 KPIs distributed among 18 practices, where order lead time and quality of delivered goods had the highest occurrence for practices (7 and 6, respectively). The majority of KPIs were non-financial, as they mainly drive the financial KPIs (Nudurupati et al., 2011). The results are theoretically underpinned by PBV (Bromiley & Rau, 2014). From a theoretical point of view, it is the first piece of research that systematically connects KPIs to an operational level of SSRES. The overview is provided in the synthesis of the studies (see Table 9).

Second, the findings from the first contribution are applied to a leading Swiss MC, resulting in a practical and fast supplier rank prediction model with robust supplier selection criterion. Through mining of primary ERP data (supplier list and order history) as well as publicly available secondary data, a data set estimating a composite KPI was created. The data set was augmented through MICE (van Buuren & Groothuis-Oudshoorn, 2011), SMOTE (Chawla et al., 2002), and bootstrapping (Cox et al., 1994), achieving a model accuracy score of 79 percent of correctly predicting whether a supplier is resilient, partially resilient, or not resilient. This is coupled with high precision (86 percent), recall (73 percent) and high AUC (80 percent). With the help of the model's prediction, buyers can automatically pre-assess new potential suppliers by utilizing previously unused ERP data. The model's supplier ranking was tested against the buyer ranking and it was found that the model outperformed the subjective evaluation and could have prevented a production halt in mid-2020, ultimately leading to a final MOE of 95%. A full explanation of this logic is provided in the results section of the full study.

The study provides a KPI guideline for assessing the evaluating the effectiveness of different SSRES practices and applying them to real-world examples. The insights from Study B demonstrate that each SSRES practice is idiosyncratic in effectiveness measurement. With the results from the first stage, practitioners can pinpoint the most relevant KPIs and track these before, during, and after a disruption. Furthermore, the results of Study B show an example of how effectiveness measurement can work. While most of the times assumptions about the damage extent during a disruption or the recovery speed must be made with an alternative scenario, Study B provides insights on how these assumptions could be navigated. Conducting an effectiveness analysis on all practices based on empirical data, however, is beyond the scope of this study and the present dissertation. Instead, this research provides an exemplary foundation for practitioners to devise their own methods based on the with/without principle or comparative scenario analysis.

## 5.4 Study C: Determining the cost of resilience: an activity-based costing approach for buyers

Following the structure of the previous sections, this section is focused on outlining Study C in terms of the research design, findings and contributions, and implications for M3.[26]

**Research design of Study C**

Study C can be considered parallel to Study B, as it represents the second component to a CEA for SSRES practices. For this study, a multiple case study design was selected to study the costs of SSRES practices, as this method allows for a broad data foundation to make both individual and comparative analyses (Yin, 2009). To find generalizable results, a theoretical sampling technique was used during the case selection, including MCs based on specific sampling criteria. The criteria demand that (1) SSRES has become one of the top strategic priorities of the MC, (2) there should be a structured buying organization within the company, (3) a minimum of 10 SSRES practices had been adopted, (4) a product or product part had suffered a disruption in the past 3 years. For increased access and convenience, case companies from Switzerland matching the criteria were chosen. The access point to estimating practice costs with ABC is *practices*. By Bromiley and Rau's (2016) definition, a practice is a set of activities that can be categorized into different types: setup activities, maintenance activities, and usage activities.

[26] Section 5.4 largely cites the equivalent full paper in Appendix C.

Primary data was collected by interviewing the case partners in two rounds. In the first round, 120-minute semi-structured interviews were conducted with each company. From the first round, the SSRES practices from Study A were filtered according to adoption by companies since January 2019. For each of the adopted practices, 3-5 activities were identified according to company-specific context. The scope, period, and frequency of execution per activity were collected to contextualize cost estimations. Initial analyses of practice and activity distribution across the SSRES capabilities and strategies were made and presented to interviewees in a second round. The interviews were recorded, transcribed, and translated from German to English. Other artifacts such as public documents and protocols from past conversations with the case companies were used to complement and validate information provided in the first round.

In the second round of interviews, a representative with the necessary access to data or specific knowledge was interviewed for 90 minutes regarding the costs of activities. These individuals were asked to prepare the necessary data for applying the ABC to this breakdown, resulting in several data points for each practice. First, the estimations of the frequency of activity execution and the incurred costs per activity execution were collected. The product of these two variables allowed for an estimation of the total investment. Second, with the total cost per activity across the disruption cycle, an allocation of costs to resource pools, including staff/personnel, material/equipment, cash, infrastructure/facilities, and information, was made by the practitioners. From this, independent resource cost drivers assigned to the individual resource pools were derived, and their individual impact on all resilience measures was estimated.

The observed timeframe was the SARS-CoV-2 *disruption cycle* from January 2019 until March 2022 (27 months) to allow for enough time before and after the beginning of the disruption. While it was a challenge to isolate the disturbance and its associated cascaded disturbances into a single disruption cycle, the interviewees were urged to focus only on the effects of this disturbance. First, a within-case analysis was carried out, providing an overview of mostly descriptive data, highlighting (among others) the proportions of cost across the categories of practices as well as the expenditure-to-PV ratio. Second, a cross-case analysis aids in (1) identifying relationships between costs and company characteristics and (2) determining patterns in resource distribution within SSRES practices.

**Findings and contributions of Study C**

Across all five cases, 21 different SSRES practices were identified, each used by at least one company. Of those, 8 practices fell within the proactive strategy (P), 8 fell within the concurrent strategy (C), and 5 fell within the reactive strategy (R). Each practice contained between 3 and 5 activities, yielding 81 activities in total (40 setup activities, 22 maintenance activities, and 19 usage activities) across pre-disruption, during-disruption, and post-disruption phases. From the collected results, several observations were made during cross-case analysis.[27]

- First, companies generally spend very little on SSRES practices compared to their procurement volume. Across all cases, an annual cost-to-PV ratio between 0.08% and 0.56% was determined. Considering the damage mitigation and recovery acceleration potential of some practices, these are generally small costs, but can have enormous impact on the company's supply-side performance and, consequently, on the service level to their customers. All of the case companies experienced a supply shortage at one point during the past three years, and all have recovered.
- Second, company size is directly proportional to spending on proactive SSRES strategies. Notwithstanding the high spread of absolute spend between companies in the respective SSRES strategies, larger companies spent a significant amount of their budgets on proactive SSRES (53% on average). Proactive practices are mainly resource-intensive in terms of personnel, considering the high wages in Switzerland in comparison to other countries. On the other hand, the smaller companies in the set have the highest expenditure on concurrent practices (56% on average). This implies that lower expenditure ratio on proactive SSRES does not cause the higher expenditure on concurrent practices but can rather be explained by the need for cash reserves.
- Third, larger companies have a broader portfolio of SSRES practices. There is also a positive relationship between the number of practices and spending on SSRES practices. Larger companies also have more leverage with suppliers and

[27] The full set of observations can be consulted in the corresponding full paper in Appendix C.

logistic service providers, as well as in-house lawyers and controlling personnel to devise, negotiate, and draft contracts.

- Fourth, personnel constituted by far the highest percentage cost, with an average of 49% over all activities across all practices and companies. This makes the two main cost drivers the number of time units worked and the salary per time unit. Furthermore, material and equipment made up a major part of some practices, especially within the concurrent strategy. Naturally, these activities were mainly related to stock.

The collection of all observations can be found in the discussion section of the full study.

Regarding M3, this study makes a considerable contribution to helping practitioners estimate the costs of their SSRES practices and become aware of different cost drivers. These costs can be aggregated to higher-order constructs to make statements about investments into strategies, capabilities, and specific resilience elements. As a versatile method, practitioners can not only use it to calculate past investments, but also apply it to make scenario analyses for the future when adopting a variety of other practices. As the results reveal estimates regarding the distribution of invested resources, they can be used to orient resource planning.

## 5.5 Synthesis of the studies: The resilience practice recommendation system

Studies A, B, and C have each provided a considerable partial contribution to this dissertation on the operationalization of SSRES for MCs. While Study A provided insights on the conceptualization of SSRES, Studies B and C each contributed a component of a CEA building on this concept. However, practitioners might still wonder how these individual findings apply to their settings in an integrated fashion, as the provided managerial contributions only illuminate partial aspects of SSRES operationalization for certain situations and companies. Therefore, a more comprehensive method for conducting a CEA in the setting of an MC is proposed and outlined below. The method represents a system[28] of different integrated parts from the individual studies used to conduct a CEA for buyers of MCs in the mechanical and electrical engineering industries. This

[28] A system is an organized collection of highly integrated parts or subparts to complete a specific purpose target (McNamara, 2006).

system would allow these buyers to identify SSRES practices to be optimized and explored. The system's objective is to increase buyer awareness of their SSRES and opportunities to build SSRES to navigate future SC disruptions that are preceded by supply-side threats.

The supply-side **Res**ilience **P**ract**i**ce **Re**commendation (**RESPIRE**) system is the culmination of this dissertation and builds on the previous studies to operationalize the concept and guide buyers to form their strategy according to internal company variables as well as external environment and disruption variables. RESPIRE is comprised of two modules: (1) the actual SSRES assessment and (2) the target SSRES assessment with an integrated practice recommendation. Each module has several inputs, which undergo procedures to generate outputs, all of which contribute to reaching the overall objective of conducting a CEA and ranking various practices according to derived criteria. Additionally, the modules and steps within the modules have interdependencies among each other. Overall, the goal of the system is prioritized over the goals of the individual components of the modules.

**Module 1: Actual SSRES assessment**

The first module aims to determine the current state of SSRES in the upstream SC of the MC. It does so by helping identify the currently adopted practices as well as the associated costs and effectiveness. Based on the effectiveness metric from the portfolio of SSRES practices are mapped to a set of SSRES capabilities via contribution scores. In the following, the individual steps are described in detail; an illustration of the steps is provided in Figure 14.

In *Step 1*, the user is presented with a list of 18 SSRES practices. These practices—categorized into proactive (P), concurrent (C), and reactive (R)—were originally adopted from Study A and interpreted in Study B according to the findings of the SLR.[29] Additionally, each practice has different adoption governance (buyer, supplier, dyad) and can be allocated to different SSRES capabilities, as demonstrated in Study A.[30] For example, P1 ("upstream risk monitoring systems") is practiced on buyer level and contributes to the capability to anticipate. Meanwhile, C2 ("information sharing with

[29] The full catalog of practices as presented in the Appendix, Section A.8.1 would overwhelm the practitioner. Therefore the union of adopted practices by the case company participants from Study B is used.
[30] For derivation purposes, objectives and elements acted as bridges to allocate practices to capabilities. In this study, we refrain from introducing these additional constructs to maintain a level of simplicity for the user.

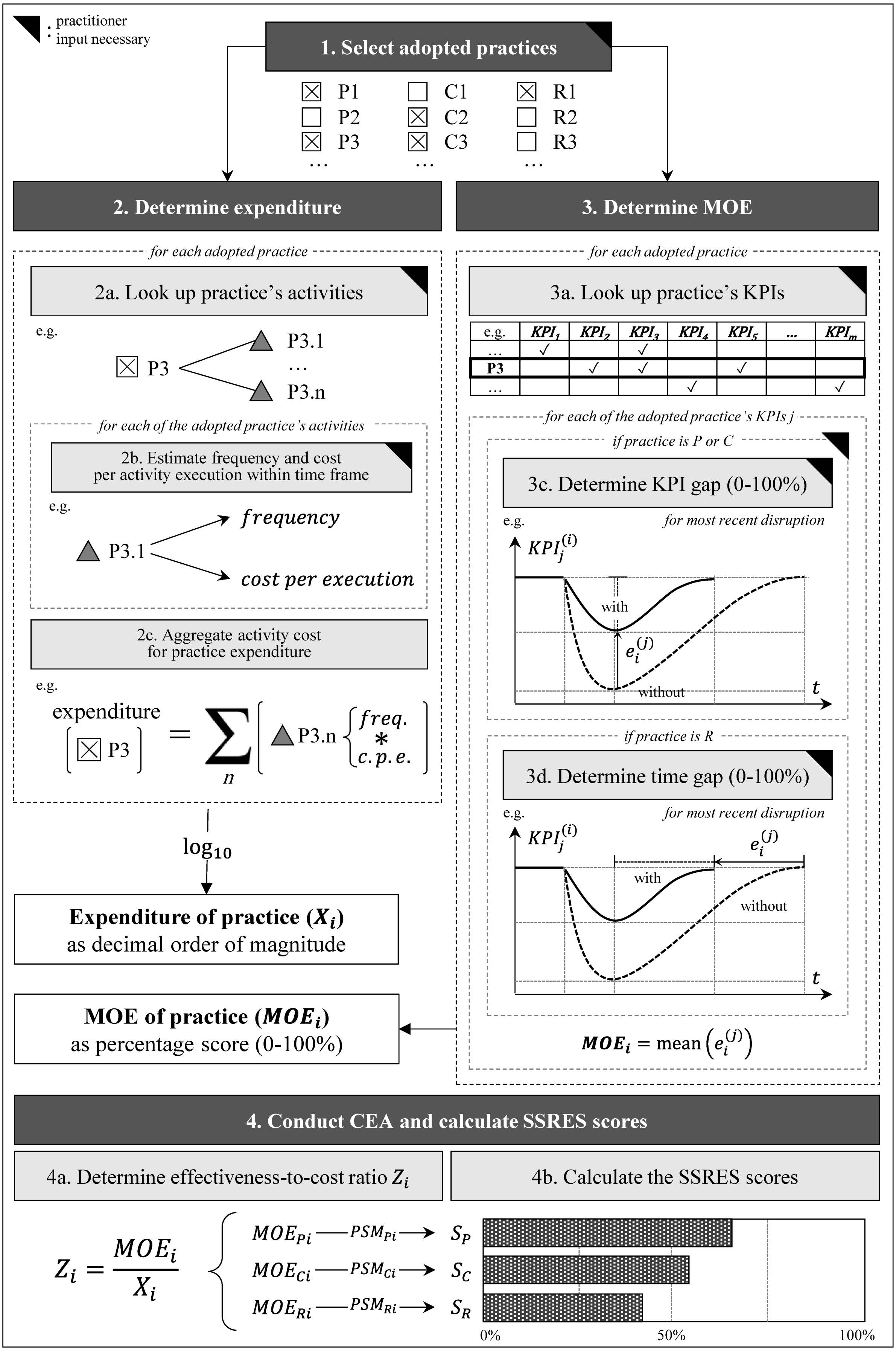


**Figure 14.** Module 1 of RESPIRE

supplier") is practiced on dyad level and contributes to the ability to respond. The adoption of practices occurs with different configurations. For RESPIRE, a set of critical suppliers or products should typically be chosen. Additionally, the table reveals the PSM scores empirically extrapolated in Study A, indicating the practice's relevance for PSM. Finally, the relevant KPIs for measuring the practice's effectiveness are provided (Study B).[31] From this list, the user selects the practices currently adopted in their buying organization. Subsequently, the user repeats Steps 2 and 3 for all selected practices. In line with PBV, it is assumed that each practice has an individual contribution to SSRES and must therefore be evaluated separately (Hof & Rideout, 1989). The full table of SSRES practices is provided in Table 9.

**Table 9.** SSRES practices with associated KPIs (adopted from Study B)

| **ID** | **Adoption level** | **Practice** | **Capability** | **PSM Score** | **Procurement ROI** | **Capacity utilization** | **Stock level** | **Order lead time** | **On-time delivery of goods** | **Supplier rejection rate** |
|---|---|---|---|---|---|---|---|---|---|---|
| P1 | Buyer | Upstream risk monitoring systems | Anticipate | 4.86 | | | ✓ | | | |
| P2 | Supplier | Continuous improvement plans | Anticipate | 4.3 | | | | | | ✓ |
| P3 | Buyer | Robust supplier selection/evaluation criteria | Anticipate | 4.72 | ✓ | | | | ✓ | ✓ |
| P4 | Buyer | Supplier training and development program | Anticipate | 5 | | | | | | ✓ |
| P5 | Buyer | Supplier relationship management system | Anticipate | 5 | | | | ✓ | ✓ | |
| P6 | Dyad | Incentive-aligning contracts | Anticipate | 4.65 | | | | | | ✓ |
| C1 | Buyer | Insourcing production | Respond | 4.23 | | ✓ | ✓ | ✓ | | ✓ |
| C2 | Dyad | Information sharing with suppliers | Respond | 4.5 | | | ✓ | | | |
| C3 | Buyer | Disruption task force team | Respond | 4 | ✓ | | | | | |
| C4 | Buyer | Usage of substitute parts in production | Respond | 5 | ✓ | | | | ✓ | ✓ |
| C5 | Buyer | Flexible transportation volumes | Adapt | 5 | | ✓ | | ✓ | | |
| C6 | Buyer | Transportation switching alternatives | Adapt | 5 | | ✓ | | ✓ | ✓ | |
| C7 | Buyer | Safety stock of critical items | Adapt | 4.9 | | ✓ | ✓ | | | |

[31] The KPIs for the MOE will be handled in Step 3.

| ID | Adoption level | Practice | Capability | PSM Score | Procurement ROI | Capacity utilization | Stock level | Order lead time | On-time delivery of goods | Supplier rejection rate |
|---|---|---|---|---|---|---|---|---|---|---|
| C8 | Buyer | Backup suppliers | Adapt | 5 | | | ✓ | ✓ | | |
| R1 | Dyad | Resource sharing with supplier | Recover | 4.68 | | | | ✓ | ✓ | ✓ |
| R2 | Buyer | Margin optimization | Recover | 4.34 | ✓ | | | | | |
| R3 | Dyad | Information sharing with suppliers | Learn | 4.5 | | | ✓ | | | ✓ |
| R4 | Buyer | Documentation and dissemination of disruption implications | Learn | 4 | | | | ✓ | ✓ | ✓ |

In *Step 2*, the costs of the individual practices are determined via the method developed in Study C. For each selected practice $i$, the user can look up the associated setup, maintenance, and usage activities (Appendix, Section C.3). In the next step, the user must provide the frequency of activity execution and the resources spent on individual activity executions since full recovery from the last disruption. Optionally, resource pools (personal, infrastructure, information, etc.) can be used to facilitate the estimations. The sum of elementwise multiplications of frequency and resources per activity $a$ over a practice's activities $A_i$ provides the cost's decimal order of magnitude of a practice $i$, i.e., the expenditure, $X_i$:[32]

$$X_i = \log_{10}\left(\sum_{a=1}^{A_i} frequency_a^{(i)} * resources_a^{(i)}\right)$$

*Step 3* is focuses on estimating the effectiveness of the adopted practices in terms of suitable KPIs to derive a suitable MOE[33]. First, the KPIs relevant for the practice (Study B) are looked up. The user then assigns each KPI of the practice a reference value

[32] The decimal order of magnitude is selected consciously due to the risk of statistical insignificance when placed in relation to the MOE. Additionally, single-digit number increase the simplicity for subsequent calculations.
[33] See Section 3.2 for more details on MOEs.

between 0% and 100% to describe the level before any disturbance or disruption impact.[34] Finally, for each KPI of a practice, the MOE is identified with the help of isolated with/without analyses or alternative scenario analyses and the ideal-typical graphs from Study B as guidance (see Figure B-1).[35] In this practice-specific analysis, a differentiation between P/C and R practices is made (see Figure 10):

The main objective of P and C practices is to mitigate the damage of the disruption (see Section 3.2), i.e., maintain the given reference KPI level as much as possible. A comparison of the KPI level at the time of maximum disruption impact with and without the practice serves to measure the effectiveness of the practice toward reaching the goal. The user is asked to provide a value between 0% and 100% describing the gap between the KPI level at maximum impact without the practice and the KPI level at maximum impact with the practice adopted. The difference provides the partial practice effectiveness score $e_j^{(i)}$ for specific KPI $j$ of a P or C practice $i$.

The main objective of R practices is to recover to the given reference KPI level or an even better one as fast as possible (see Section 3.2). Therefore, the difference in recovery speed between the scenario without the practice and with the practice provides an indication toward the effectiveness. Like the former case, the user is asked to provide a value between 0% and 100% describing the time gap between the horizontal axis intercepts of the two scenarios. The difference provides the partial practice effectiveness score $e_j^{(i)}$ for specific KPI $j$ of an R practice $i$.

The determination of the partial effectiveness scores can be either conducted with in-depth methods based on empirical data or through subjective evaluations. While the latter is more prone to bias, the former requires a considerable data foundation. In either case, the results must be scaled to correspond to an MOE between 0% and 100%. In-depth methods such as Study B generally require a considerable amount of data yet provide more plausibility to the estimations. As soon as the partial practice effectiveness scores have been determined over all KPIs $j$, a practice's total measure of effectiveness $MOE_i$ is calculated by their mean:

[34] Providing the reference value is not strictly necessary, as the MOE relies on the gap of the KPI curve in terms of value and time. However, a reference value aids in identifying the with and without values for comparative analysis.

[35] Figure 14 merely shows an exemplary MOE graph. Figure B-1 in Study B provides a full overview of all KPIs for P/C, and R practices.

$$MOE_i = \text{mean}\left(e_i^{(j)}\right)$$

With the help of the formula, the practices can be individually evaluated according to their effectiveness-expenditure ratio $Z_i$:

$$Z_i = \frac{MOE_i}{X_i}$$

After the effectiveness scores $MOE_i$ for all practices $i = \{1, \dots, n\}$ have been determined, they must be mapped to the final SSRES strategies (proactive, concurrent, strategy). As each practice holds a unique contribution to its allocated strategy, this contribution can be assumed the empirically validated importance of the practice to the buying organization. Therefore, the PSM scores of the individual practices act as weights to define the contribution of the practice to a strategy. The weighted mean of effectiveness-to-expenditure ratios over all selected practices allocated to a strategy multiplied with a practice diversification score[36] which makes up the final score:

$$S_k = \frac{(\#\, selected)_k}{(\#\, all)_k} * \frac{\sum_i Z_i^{(k)} * PSM_i^{(k)}}{\sum_i PSM_i^{(k)}} \in [0,1]$$

This process is repeated for all three strategies (proactive, concurrent, and reactive). The strategy scores are RESPIRE's estimation of the current state of SSRES.

**Module 2: Target SSRES assessment**

The second module of RESPIRE is dedicated to assessing the target state of SSRES by recommending capabilities based on inputs of contingency variables and ultimately suggesting a set of practices with the highest effectiveness-to-cost ratio. An illustration of the steps is provided in Figure 15.

[36] The diversification score entails the ratio of selected SSRES practices to all SSRES practices within that strategy.

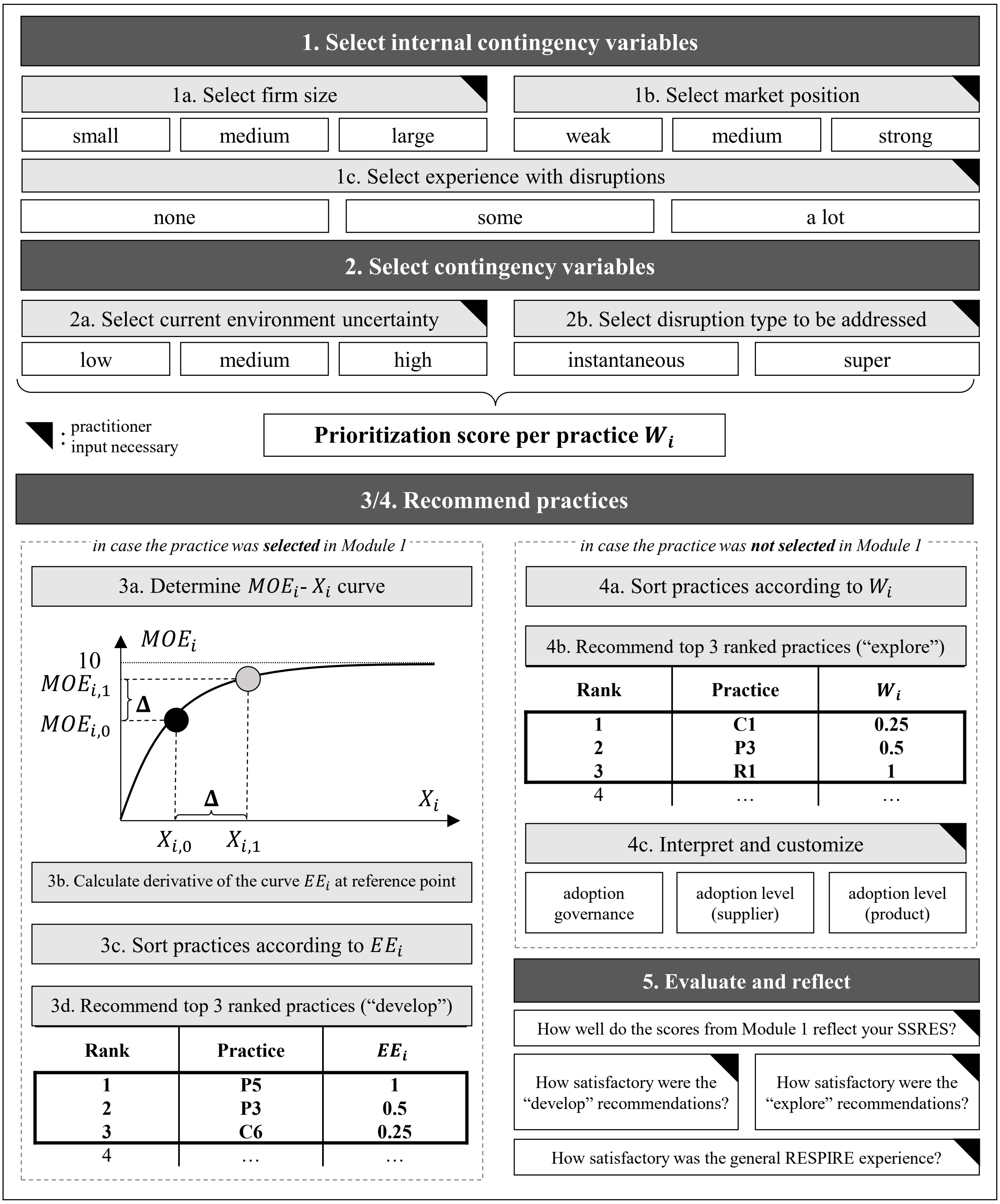


**Figure 15.** Module 2 of RESPIRE

In *Steps 1 and 2*, internal and external contingency variables (respectively) are requested from the practitioner. These reward or penalize specific practices based on their phase, adoption governance, or associated SSRES element in a pre-recommendation step. Internal variables, as identified in Study A, include company size, market position, and experience with disruptions. In the following, the implications of the respective variable manifestations are described.

- The *company size* can be generally measured in terms of revenue, employees, or capital (Orlitzky, 2001). The user is presented with three options of variable manifestation: small[37] (s), medium-sized[38] (m), and large[39] (l). While larger companies have more expenditure capacity into SSRES practices, smaller companies must maintain cash reserves before disruptions and focus on steadily growing revenue streams (Melnyk et al., 2021). Therefore, smaller companies should focus more on C practices to mitigate disruption damage. Medium-sized companies should extend this strategy to R practices. Meanwhile, larger companies should have no preference of P, C, and R practices.
- The *market position* helps determine the prioritization of SSRES practices in terms of adoption governance. The user is presented with three options of variable manifestation: weak (s), moderate (m), and strong (s). A higher dependency of suppliers on the MC implies a larger upstream lever and thus a strong market position. Companies with strong market positions can generally incentivize suppliers to adopt practices in their organization or collaborate on the adoption of practices on the dyad level. Meanwhile, companies with weaker market position should prioritize company-internal practices and should thus penalize the adoption of dyadic or supplier practices. A stronger market position encourages the adoption of external practices. Companies with a moderate market position prioritize neither internal nor external practices.
- The *level of experience* is strongly related to knowledge about disruptions sourced through internal and external social capital. The user is presented with three options of variable manifestation: low (l), medium (m), and high (h). Less experienced companies must compensate for their lack of internal social capital by putting a focus on sourcing experience from outside (Ozanne et al., 2022), and in this case from suppliers. Therefore, dyadic practices falling within the element *knowledge management (pre-disruption)* and *knowledge management (post-disruption)*, as well as information sharing should be prioritized for both low and

[37] corresponding to less than 10 million Swiss francs revenue
[38] corresponding to between 10 million and 100 million Swiss francs revenue
[39] corresponding to more than 100 million Swiss francs revenue

medium experience levels. More experienced companies often already have processes and routines in place, which stem from the applied knowledge within the company. Therefore, no practice prioritization is made for this category of companies.

Furthermore, the recommendation of practices includes external contingency variables that pertain to the general uncertainty level and the type of disruption to be addressed with this new practice portfolio.

- The *level of uncertainty* (as described in Section 2.2) consists of a fixed, non-influenceable and a dynamic, influenceable component. The user is presented with three options of variable manifestation: low (l), medium (m), and high (h). Environmental uncertainty exists before, during, and after disruptions, but is generally the highest before and during disruptions (Cardoso et al., 2015). As the deployment of SSRES capabilities can reduce the dynamic uncertainty component, medium and high uncertainty increases the need for proactive and concurrent strategies.
- Like uncertainty, the *disruption type* has an influence on the adoption of practices based on their phase of usage. As described in Section 2.2, research mainly distinguishes between instantaneous disruptions (i) and super disruptions (s) (Ivanov, 2021b). Instantaneous disruptions, characterized by their low but not negligible probability of occurrence, sharp decline, short disruption duration, and fast recovery, generally require a focus on all three phases. For a super disruption, which generally has a longer disruption duration, proactive SSRES concurrent and reactive practices are prioritized, as the during- and post-disruption phases generally last longer and require more patience and resources.

A high penalty on prioritization (↓↓) corresponds to a weight of 0, a penalty (↓) corresponds to a weight of 0.5, a neutral stance (•) to 1, a reward on prioritization (↑) to 1.5, and a high reward on prioritization (↑↑) to 2. The full overview is provided in Table 10.

**Table 10.** Contingency variables and effects on practices

| ID | internal | | | | | | | | | external | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Company size ($cs$)** | | | **Market position ($mp$)** | | | **Experience level ($el$)** | | | **Uncertainty level ($ul$)** | | | **Disr. type ($dt$)** | |
| | **s** | **m** | **l** | **w** | **m** | **s** | **l** | **m** | **h** | **l** | **m** | **h** | **i** | **s** |
| **P1** | • | • | • | • | • | • | • | • | • | • | ↑ | ↑↑ | • | • |
| **P2** | • | • | • | ↓↓ | • | ↑↑ | • | • | • | • | ↑ | ↑↑ | • | • |
| **P3** | • | • | • | • | • | • | • | • | • | • | ↑ | ↑↑ | • | • |
| **P4** | • | • | • | • | • | • | • | • | • | • | ↑ | ↑↑ | • | • |
| **P5** | • | • | • | • | • | • | • | • | • | • | ↑ | ↑↑ | • | • |
| **P6** | • | • | • | ↓ | • | ↑ | • | • | • | • | ↑ | ↑↑ | • | • |
| **C1** | ↑ | ↑ | • | • | • | • | • | • | • | • | ↑ | ↑↑ | • | ↑ |
| **C2** | ↑ | ↑ | • | ↓ | • | ↑ | ↑↑ | ↑ | • | • | ↑ | ↑↑ | • | ↑ |
| **C3** | ↑ | ↑ | • | ↓ | • | ↑ | • | • | • | • | ↑ | ↑↑ | • | ↑ |
| **C4** | ↑ | ↑ | • | • | • | • | • | • | • | • | ↑ | ↑↑ | • | ↑ |
| **C5** | ↑ | ↑ | • | • | • | • | • | • | • | • | ↑ | ↑↑ | • | ↑ |
| **C6** | ↑ | ↑ | • | • | • | • | • | • | • | • | ↑ | ↑↑ | • | ↑ |
| **C7** | ↑ | ↑ | • | • | • | • | • | • | • | • | ↑ | ↑↑ | • | ↑ |
| **C8** | ↑ | ↑ | • | • | • | • | • | • | • | • | ↑ | ↑↑ | • | ↑ |
| **R1** | • | ↑ | • | ↓ | • | ↑ | • | • | • | • | • | • | • | ↑ |
| **R2** | • | ↑ | • | • | • | • | • | • | • | • | • | • | • | ↑ |
| **R3** | • | ↑ | • | ↓ | • | ↑ | ↑↑ | ↑ | • | • | • | • | • | ↑ |
| **R4** | • | ↑ | • | • | • | • | ↑↑ | ↑ | • | • | • | • | • | ↑ |

Finally, a total prioritization (or weight) factor $W_i$ for a practice $i$ is introduced, which makes up a product of all internal and external contingency variable weights:

$$W_i = \prod w_i^{(int)} * \prod w_i^{(ext)} = \left(w_i^{(cs)} * w_i^{(mp)} * w_i^{(el)}\right) * \left(w_i^{(ul)} * w_i^{(dt)}\right)$$

The larger the value of $W_i$, the more a practice should be prioritized.

In the final steps, the user is presented with two different types of recommended practices in the categories "optimize" – for selected practices with existing effectiveness data (Step 3) – and "explore"– for non-selected practices with no prior adoption experience (Step 4). In the following, the derivations of practice recommendation for each case are described in detail.

In the case that practices have already been selected, a connection between expenditure $X_i$, effectiveness $MOE_i$, and prioritization $W_i$ for a practice $i$ can be determined. According to Study B, the effectiveness of a practice based on a specific KPI converges to a certain value independent of the expenditure. In other words, a higher expenditure into a practice has exponentially diminishing effects. Mapping the expenditure to effectiveness calls for the use of a generalized logistic function, also known as Richard's curve, with its horizontal axis intercept at (0,0) and convergence towards the maximum value 1, corresponding to 100% effectiveness. Generalized logistic functions are often used in epidemiological and medical contexts to model population growth or virus spread (P. Wang et al., 2020). The measure of effectiveness $MOE_i$ is introduced, taking the expenditure $X_i$ and a practice-specific shape parameter $k_i$ as inputs.

$$MOE_i(X_i) = \frac{\exp(k_i X_i) - 1}{\exp(k_i X_i) + 1} \in [0,1]$$

The shape parameter $k_i$ influences "expenditure efficiency", i.e., the degree of curvature. Independent $k_i$, as $X_i$ approaches infinity, the following statement can be made for $MOE_i$:

$$\lim_{X_i \to \infty} MOE_i = 1 \equiv 100\%$$

As initial values for the expenditure $X_{i,0}$ and the effectiveness $MOE_{i,0} = MOE_i(X_0)$ are provided from Module 1, the expenditure-to-effectiveness mapping with inserted initial values can be solved for the shape parameter $k_i$ for a practice $i$:

$$k_i = \frac{1}{X_{i,0}} \log\left(\frac{1 + MOE_{i,0}}{1 - MOE_{i,0}}\right)$$

Inserting $k_i$ into $MOE_i$ results in the final formula for mapping the practice expenditure to effectiveness:

$$MOE_i(X_i) = 1 - 2\left[\left(\frac{1 + MOE_{i,0}}{1 - MOE_{i,0}}\right)^{\frac{X_i}{X_{i,0}}} + 1\right]^{-1}$$

The practices are then ranked according to the derivative of $MOE_i(X_i)$ at the point $X_{i,0}$ and weighted by $W_i$, representing the "expenditure efficiency" $EE_i$:[40]

$$EE_i = \left.\frac{\partial MOE_i(X_i)}{\partial X_i}\right|_{X_i = X_{i,0}} * W_i = \frac{2 * W_i}{X_{i,0}} * \frac{F * \log(F)}{[F + 1]^2}$$

[40] For small $k_i$ the input value of the target function is decreased. The rate of effectiveness is thereby diminished, meaning that a higher expenditure is less 'efficient'. A large $k_i$ on the other hand, essentially a reward, implies that a higher expenditure is more 'efficient'.

$$\text{where } F = \frac{1 + MOE_{i,0}}{1 - MOE_{i,0}}$$

The highest ranked practices then constitute those which have high potential to be further developed.

In the case of non-selected practices, the prioritization $W_i$ provides a guideline for which practices should be explored for deeper analysis.[41] Step 4c is dedicated to the interpretation and customization of recommended practices to explore.

In a final evaluation and reflection step, the practitioner's satisfaction of the results of both Module 1 and 2 provided are to be evaluated. Regarding Module 1, it is asked how well the scores from Module 1 reflect the SSRES of the MC. Regarding Module 2, it is asked how satisfactory the "develop" and "explore" recommendations were to the practitioner and how well they were aligned with the plans of the MC. Finally, a general question inquires the general experience satisfaction of conducting RESPIRE.

**Guideline on usage and limitations**

RESPIRE should be used by practitioners working in or overseeing the procurement department of MCs. These can include CPOs, strategic buyers, and risk managers. As the insights from the system entail strategic components and are mainly concerned with resource allocation, a communication line between the user and management should be established. A practitioner should use RESPIRE in regular intervals to achieve comparability across different periods of time, and especially during different stages of a disruption. Quarterly usage is recommended as a guideline. As this method is underpinned with RCT, it is assumed that the user makes rational decisions according to the metrics calculated. Important to note is that RESPIRE will not provide an amount in Swiss francs to invest, as it solely aims to achieve comparability and derive a ranking between the practices. RESPIRE provides the blueprint of a ranking metric $EE_i$, which should not be interpreted for investment planning.

**RESPIRE case study**

RESPIRE has been tested with a Swiss MC in the mechanical engineering industry, for which qualitative interview data and quantitative supplier and cost data was collected in

[41] As no empirical data exists for the non-selected practices, too many assumptions need to be made and would render the recommendation of non-selected practices highly error prone.

all three studies. Complementary data collection through a series of three 60-minute interviews with the CPO and head of controlling was performed to account for missing information and to complete the two modules. The cascade of disturbances driven by measures to contain SARS-CoV-2 caused a super disruption within a set of key raw materials supply markets for the MC. Against this backdrop, the adoption configuration of practices primarily for this supply market was considered throughout this case study. This supply market comprises two different critical items for the subsequent processing and assembly in Switzerland.

Following Module 1, the first and second steps entail the selection of adopted practices within the specified time frame and the evaluation of effectiveness. The effectiveness calculations based on empirical data have been conducted for one practice with the results of Study B and then translated to a percentage value. For the remaining practices, the MOE has been determined through subjective evaluations in percentage.[42] A full overview of adopted practices and calculations is provided in **Error! Reference source not found.**.

**Table 11.** Practices selected and evaluated by the MC

| ID | Adoption level | Strategy | MOE method | $X_i$ | $MOE_i$ | $Z_i$ | $PSM_i$ | $S_k$ |
|---|---|---|---|---|---|---|---|---|
| P2 | Supplier | Proactive | Subjective | 4* | 10%** | 0.03 | 4.30 | 53.43% |
| P3 | Buyer | Proactive | Empirical[43] | 5* | **95%*** ** | **0.20** | 4.72 | |
| P4 | Buyer | Proactive | Subjective | 5* | 50%** | 0.10 | 5.00 | |
| P6 | Buyer | Proactive | Subjective | 5* | 50%** | 0.10 | 4.65 | |
| C6 | Buyer | Concurrent | Subjective | 6* | 75%** | 0.13 | 5.00 | **73.29%** |
| C7 | Buyer | Concurrent | Subjective | 6* | 80%** | 0.13 | 4.90 | |
| C8 | Buyer | Concurrent | Subjective | 5* | 65%** | 0.13 | 5.00 | |
| R2 | Buyer | Reactive | Subjective | 5* | 30%** | 0.06 | 4.34 | 27.45% |
| R3 | Dyad | Reactive | Subjective | 4* | 25%** | 0.06 | 4.50 | |

*Value derived based on results from Study C; **Value derived from subjective evaluation in the complementary case study; ***Value derived based on results from Study B

Since 2021, the MC incentivizes a key supplier in this market to adopt and follow continuous improvement plans (P2). As a proactive practice, effectiveness is measured according to its damage mitigation potential. Considering that communication was not very good, the effectiveness score in terms of supplier rejection rate (10%) was low,

[42] The effectiveness calculation based on empirical data for all practices is beyond the scope of the present dissertation.
[43] For this case calculation, it is assumed that the robust supplier selection/evaluation criteria model developed in Study B has been adopted by the MC.

leading to a total score of 10%. Furthermore, the MC introduced the usage of supplier selection/evaluation criteria (P3) for continuous supplier evaluation. In its case study, Study B introduces robust supplier evaluation criteria as a tree-based random forest model and concludes that another supplier for the same part would have been prioritized if that model had been selected. This results in 95% effectiveness based on the composite KPI that was constructed from matching. Next, the MC has a regular supplier training and development for A suppliers, including those critical suppliers observed for this analysis (P4). With one KPI matching this proactive practice, the interviewees subjectively rated a potential mitigation of supplier rejection rate at 50%. For most critical suppliers, the MC have negotiated incentive-aligning contracts, which guarantees minimum order quantities (P6). This is tied to supplier rejection rate and is evaluated as 50% as well.

Regarding concurrent practices, the MC has set up transportation switching alternatives and paid high premiums for insurance (C6). Regarding order lead time and on-time delivery, this practice was evaluated as 70% and 80% respectively, leading to a total MOE of 75%. Furthermore, C7 was practiced meticulously from the beginning of the time period. The damage of a stockout during material flow disruption was reduced with the MOE of 80%. During a period where the supplier could not deliver material via ship, the MC temporarily switched to air transport while activating and mobilizing the backup supplier (C8). This practice had an effectiveness of 50% on stock level and of 80% on order lead time, leading to a total MOE of 65%.

In terms of reactive practices, the effectiveness is measured by the potential increase in recovery speed after a disruption. The MC undertook measures to focus production on the product with higher margin to improve its profitability at the beginning of 2022 (R2). Naturally, the matched KPI is procurement ROI. An internal calculation revealed that the procurement ROI would recover around 30% faster with this practice than without this practice, leading to an MOE of 30%. Furthermore, the communication line with the supplier was very active for matching supply and demand and informing each other on the latest developments (R3). A subjective evaluation of MOE resulted in a 20% MOE for the stock level and 30% effectiveness for the supplier rejection rate, leading to a 25% total MOE.

The cost calculations have been partially adopted from Study C; however, a second pass was conducted for most practices. The MC spent CHF 497,000 for 9 practices with a 61% additional expenditure into concurrent over proactive practices. The highest expenditure was made in the concurrent practices, especially C6 and C8.

The analysis yields that P3 and C6 are currently the most effective practices. Going further, the effectiveness-to-cost ratio $Z_i$ reveals the highest values for P3 and C7 and the lowest value for P2. Incidentally, the highest $Z_i$-values coincide with the highest $MOE_i$ (P3). Finally, the strategy scores have been determined as $S_P = 53.43\%$, $S_C = 73.29\%$, and $S_R = 27.45\%$. This indicates that the concurrent SSRES of the MC is the most developed, while the reactive SSRES is the least developed. After presentation of these scores to the practitioners, they responded that it coincided well with the observations made by the practitioners; while damage mitigation was very effective, the recovery took longer than expected.

For Module 2, the case partners of the MC indicated the following manifestations of the contingency variables:

- *Company size*: medium
- *Market position*: weak
- *Experience level*: medium
- *Uncertainty level*: high
- *Disruption type*: super

Following the prioritization logic from Table 10, $W_i$ for the individual practices, both adopted and not adopted, could be derived (see Table 12). Additionally, for all adopted practices, $MOE_i$ and $Z_i$ was determined for the practice rank (Step 4b in Figure 15**).**

**Table 12.** Recommendations of SSRES practices to be developed or explored

| ID | Adopted? | $w_i^{(fs)}$ | $w_i^{(mp)}$ | $w_i^{(el)}$ | $w_i^{(ul)}$ | $w_i^{(dt)}$ | $W_i$ | $EE_i$ | Recommendation |
|---|---|---|---|---|---|---|---|---|---|
| **P1** | | 1 | 1 | 1 | 2 | 1 | 2 | | |
| **P2** | ✓ | 1 | 1 | 1 | 2 | 1 | 2 | 0.050 | |
| **P3** | ✓ | 1 | 1 | 1 | 2 | 1 | 2 | 0.071 | |
| **P4** | ✓ | 1 | 1 | 1 | 2 | 1 | 2 | 0.165 | |
| **P5** | | 1 | 1 | 1 | 2 | 1 | 2 | | |
| **P6** | ✓ | 1 | 1 | 1 | 2 | 1 | 2 | 0.165 | |
| **C1** | | 1.5 | 1 | 1 | 2 | 1.5 | 4.5 | | explore |
| **C2** | | 1.5 | 1 | 1.5 | 2 | 1.5 | 6.75 | | explore |
| **C3** | | 1.5 | 1 | 1 | 2 | 1.5 | 4.5 | | explore |

| ID | Adopted? | $w_i^{(fs)}$ | $w_i^{(mp)}$ | $w_i^{(el)}$ | $w_i^{(ul)}$ | $w_i^{(dt)}$ | $W_i$ | $EE_i$ | Recommendation |
|---|---|---|---|---|---|---|---|---|---|
| **C4** | | 1.5 | 1 | 1 | 2 | 1.5 | 4.5 | | explore |
| **C5** | | 1.5 | 1 | 1 | 2 | 1.5 | 4.5 | | explore |
| **C6** | ✓ | 1.5 | 1 | 1 | 2 | 1.5 | 4.5 | 0.319 | develop |
| **C7** | ✓ | 1.5 | 1 | 1 | 2 | 1.5 | 4.5 | 0.297 | develop |
| **C8** | ✓ | 1.5 | 1 | 1 | 2 | 1.5 | 4.5 | 0.403 | develop |
| **R1** | | 1.5 | 1 | 1 | 1 | 1.5 | 2.25 | | |
| **R2** | ✓ | 1.5 | 1 | 1 | 1 | 1.5 | 2.25 | 0.127 | |
| **R3** | ✓ | 1.5 | 1 | 1.5 | 1 | 1.5 | 3.375 | 0.202 | |
| **R4** | | 1.5 | 1 | 1.5 | 1 | 1.5 | 3.375 | | |

The already adopted practices recommended for further expenditure to their effectiveness potential include C8, C6, and C7. The high prioritization of concurrent practices, which was mainly driven by the combination of the medium company size, the currently high uncertainty, and the super disruption type, highly contributed to this selection. Regarding not adopted practices, RESPIRE recommends an even broader portfolio of concurrent SSRES practices. The highest weighted practice is information sharing with suppliers with $W_{C2} = 6.75$. The decisive factor here was the medium experience level with disruptions and the need for externally sourcing knowledge, doubling the weighting regarding the other concurrent practices.

**Interpretation, evaluation, and reflection of the results**

After these results were presented to the representatives of the MC, a round of confirmatory interviews was conducted with the CPO and the risk manager.

In general, the recommendations for further development (C8, C6, C7) were welcomed. Regarding C8, the MC has installed a backup supplier for one critical part, however, it will seek to expand this practice to other product groups. Before application of RESPIRE, the MC was working on procedures in their procurement to make dual sourcing mandatory for a set of parts. RESPIRE gave C8 the highest score from the three, as higher potential due to the lower $X_{C8}$ and $MOE_{C8}$ values compared to C6 and C7. Regarding C6, transportation switching alternatives have been negotiated with all logistics service providers. Potentially, alternative logistics service providers could be contacted, however, in the eyes of the case partners, this is not a priority for now. Regarding C7, the MC is considering increasing their safety stock from 20% to 30% of yearly order volume for both critical parts. This allows a longer survival time during periods when replenishment is not possible. Hence, in at least two out of three cases, these insights confirm the recommendations of RESPIRE regarding the practices to develop.

The practices to explore (C2, C1, C3, C4, C5) were individually addressed and discussed in the interviews. These practices must first be investigated upon their adoption configuration regarding adoption level. Regarding C2, the MC is “definitely planning” the deployment in resources to develop and improve information channels between SC partners to increase the transparency and open up the door for further resilience practices such as resource sharing. Regarding C1, the MC would like to keep focusing on its core competencies and avoid insourcing production as much as possible. This would require heavy investments, which are not feasible according to internal calculations. Regarding C3, a disruption task force with experienced people would have been beneficial to a certain extent; the management of the MC has already spoken to experts and their decisions prevented the MC from having major production halts or revenue losses. However, a disruption task force would have “probably been more efficient” (CPO, MC). Regarding C4, the usage of substitute parts in production is not feasible in the industry and leads to heavy quality losses, which affects customer satisfaction. The MC does not see itself as ready to make this compromise. Finally, regarding C5, the MC was intrigued by the adoption of flexible transportation volume agreements with the supplier and logistics service providers. This could help during times of great fluctuation and could become strategically important when competitors aim to buy entire stocks of suppliers for strategic gaming. Summing up, the highest ranked practice to explore was highly welcomed by the MC. While C3 and C5 were similarly embraced for adoption in specific configurations, C2 and C4 did not seem plausible in the context of the MC. Hence, a total of three out of five practices to explore were confirmed for validity.

Surprisingly, RESPIRE recommended mainly concurrent practices instead of reactive practices, considering the low score of $S_R$. The already high score of $S_C$ would be increased after development and adoption of the recommended practices. Thereby, both internal and external contingency variables could change (e.g., experience with disruptions, environment uncertainty) and recommendations in a subsequent cycle would shift.

The case partners confirmed that they would have to use RESPIRE regularly, around once a quarter, to re-assess their SSRES and how the change of both internal and external contingencies influence future recommendations.

# 6 Conclusion of the research on supply-side resilience operationalization for manufacturing companies

Following an in-depth analysis of the individual studies in Chapter 5, Chapter 6 aims to summarize, contextualize, and synthesize the respective contributions in a reflective manner. Section 6.1 provides the answers to the research questions and outlines the theoretical contributions. Section 6.2 highlights the managerial implications and discusses how the findings can contribute to successful operationalization of SSRES by expanding the individual studies' contributions on a more general level. Finally, Section 6.3 addresses the limitations of this dissertation and presents ideas for future research.

## 6.1 Overall contributions of the studies

This section seeks to situate the dissertation's results within the larger research context. After the answers to the research questions are provided, the section concludes in a reflection on the theoretical findings of the individual studies to address the theoretical shortcomings.

**Answers to the research questions**

Each study was focused on a different phase in the operationalization of SSRES; while Study A placed the theoretical constructs of SSRES in a coherent structure, Study B presented a method of measuring effectiveness for a SSRES practice, and Study C investigated potential for estimating the effort of adopting, maintaining, and using SSRES practices. The answers to the research questions posed in Section 3.4 are outlined below.

Study A, which reveals a catalog of SSRES practices, provides answers to $RQ1_a$, $RQ1_b$, and $RQ1_c$. Concerning $RQ1_a$, the study identifies those theoretical constructs mentioned in the literature that are tied to general SC resilience and constrains them for PSM. By applying PBV, the study can set higher-order constructs in relation to lower-order constructs to propose a hierarchy of explanatory variables for SSRES. This concept suggests that SSRES can be seen as a self-learning feedback process, in which the manifestation of the variables dynamically and continuously adapt between and with each disruption cycle. Knowledge of past disruptions is a key driver to SSRES. Regarding $RQ1_b$, a catalog of 64 SSRES practices is identified and allocated to different objectives, elements, capabilities, strategies, and phases. The adoption configuration of the practices differs and must be defined individually. Finally, regarding $RQ1_c$, the breadth of practice adoption varies individually depending on internal contingency variables including market position, experience, and resources, as well as external contingency variables such as phase and type of disruption. CT theoretically underpins the result that these contingency variables have an influence on the choice and effectiveness of SSRES practices. For example, while larger companies should build a broad portfolio of practices across all disruption phases, smaller companies should tend to focus on ad-hoc, concurrent practices to save capital for continuous re-investments. The study contributes to the overarching research objective ($RO_0$), as it builds the foundation of subsequent SSRES operationalization through rigorous conceptualization.

Study B, which investigates the connection between KPIs and SSRES practices and applies them in a case study, provides answers to $RQ2_a$ and $RQ2_b$. Regarding $RQ2_a$, this study finds the 6 most common KPIs in connection with a selection of 18 SSRES practices. This gives guidance as to which KPI to measure effectiveness in during the adoption, maintenance, and setup of an SSRES practice. The KPIs from the buyer perspective are classified into different targets (buyer, supplier). Examples include the stock level, the order lead time, and the supplier rejection rate. It is confirmed that non-financial KPIs drive financial KPIs. Regarding $RQ2_b$, the SSRES practice effectiveness can be measured by means of the with/without principle or an alternative scenario analysis. To exemplify the latter, the KPI-practice matches were applied to the adoption of robust supplier selection criteria in a real-world case. A machine learning-based supplier ranking model was developed as a selection criteria system for the subsequent effectiveness evaluation. According to the model, a different supplier for a critical product would have been chosen before the disruption, resulting in a prevention of material flow disruptions and 95% higher effectiveness. The model thereby represents one of many possible methods of effectiveness measurement. The study contributes to $RO_0$, as it makes up one essential measurement component of the CEA.

Study C, which examines the allocation of cost to an SSRES practices, provides answers to $RQ3_a$ and $RQ3_b$. Grounded in the conceptualization based on PBV from Study A, the study breaks down practices into a number of activities. With the help of these activities, practitioners are able to estimate the frequency and expenditure per activity execution, considering the distribution of expenditure among the resource pools including staff/personnel, material/equipment, cash, infrastructure/facilities, and information. In answering $RQ3_a$ this study provides an overview of all activities and associated cost elements and resource pools for all practices. Based on this breakdown, the costs can be aggregated to different practice bundles. Thereby, hidden costs and the resource distribution into SSRES can be revealed. This study responds to $RO_0$ by providing the second essential measurement component of the CEA.

Finally, the synthesis of the studies ties the methods and results together in RESPIRE, a supply-side resilience practice recommendation system consisting of two main modules: a versatile SSRES assessment and an adaptable practice analysis system to recommend a set of practices to develop and explore. In the first module, the SSRES concept based on PBV from Study A is used as a foundation. The measurement methods from Studies B and C are integrated to provide an overview of the cost-effectiveness over a portfolio of SSRES practices. In the second module, the contingency variables derived in Study A aid in the ranking of both adopted practices to further develop and new practices to explore. RESPIRE integrates the individual studies for ultimately achieving $RO_0$.

**Theoretical contributions**

Sections 5.2 through 5.5 detail the theoretical contributions of all three studies as well as the synthesis of the studies. In considering the dissertation project as a whole, the following section identifies the combined theoretical contributions and relates them to the derived theoretical shortcomings (Section 1.2). Although the dissertation is anchored in SCRM, the contributions also disperse into the literature on PSM as well as strategic cost management.

TS1, which refers to the lacking transfer of SC resilience to the procurement setting, manifests itself at least threefold in the literature in: (1) an undifferentiated treatment of organizational and network resilience, (2) the lack of precision regarding the adoption of SSRES measures, and (3) the dearth in literature to conceptualize SSRES. This dissertation addresses these shortcomings by providing a theoretically underpinned concept of SSRES, the upstream-facing way directly tackling the source of disruptive risks. By providing an empirically proven catalog of SSRES practices, the dissertation as a whole contributes to the purchasing and supply management literature by delimiting the breadth of practices to the responsibility sphere of decision-makers in procurement and paving the path for more specific research on procurement-specific practices. By providing an SSRES practice adoption configuration system, including the adoption governance and level, the study adds more precision and concrete options for practice customization.

TS2, which addresses the abstract formulation of practice within the resilience context, is manifested in the misalignment of definitions regarding lower-order constructs such as SSRES practices and activities. Making practices hard to grasp from a managerial point of view, this misalignment blurs theoretical rigor when using these practices for further analysis. The present dissertation makes use of PBV to theoretically ground the concept initially and apply it to multiple situations with different contexts. This enables the bottom-up aggregation of activities to practices, practices to objectives, objectives to elements, elements to capabilities, capabilities to strategies, and strategies to phases. Hence, the way has been cleared for operationalization by drawing on concrete constructs. The dissertation not only contributes to the general literature on SSRES, but also proposes an extension of PBV by knowledge and resource elements. This calls for the integration of PBV with RBV and KBV, a compatibility study for future research to deepen.

TS3 emphasizes the lack of holistic cost-effectiveness measurement methods for operationalizing SSRES. As the dissertation reveals, there is a considerable gap in literature between specific, complex operations research models and abstract, purely qualitative strategical studies that attempt SSRES operationalization. The dissertation fills this gap by drawing on the qualitative conceptualization and transferring it to an adaptable, quantitative setting driven by practitioner inputs. The dissertation's synthesis addresses the shortcomings by proposing RESPIRE, a two-module SSRES practice recommendation system that finds a balance between complex operations research literature and qualitative strategic management literature. While it makes use of quantitative metrics to rank individual practices according to their suggested prioritization, the results are validated with the help of evaluation interviews. The mixed methods triangulation procedure aids to ground the calculations. RESPIRE adds to the interface of SCRM and PSM literature by opening a new field of SSRES management, i.e., the management of practices specifically addressing disruptive upstream risks.

## 6.2 Managerial implications

Buyers in MCs with global SCs face the various challenges outlined in Section 1.1. Since the 1980s, the world has witnessed a globalization trend characterized by a lowering in value creation depth resulting from outsourcing, the rise in cost pressure on suppliers, and reduction lifecycles and capital commitment through new managerial concepts and technology. In the light of increasing and intensifying unexpected supply disruptions, the prioritization of efficiency over redundancy has been curbed. Supply-side resilience has become a crucial element in a MC's strategy in the face of rising environmental uncertainty and confronts decision-makers with the challenge of effectively adopting and managing SSRES practices. The usage and application of tools and methods that provide the necessary foundation to make decisions navigating this changing environment as a buyer become increasingly important.

**Overview of SSRES operationalization for MCs**

This research lays the groundwork to tackle this challenge and provide the necessary means to make founded management decisions. Specific managerial insights on aspects of SSRES conceptualization and practice identification, effectiveness measurement, and cost measurement are presented in Sections 5.2 to 5.4. A resulting method derived from the insights for practitioner use is presented in Section 5.5. This section provides a holistic, integrative method for practitioners to make CEA on their SSRES practices. So far, no research has presented a similar method. Managerial challenges (M1-M3) are considered below.

*M1* is mainly concerned with the unclear conceptualization of SSRES and the identification of SSRES practices. While buyers and supply managers accept that resilience is important, they are overwhelmed with characterizing it and applying resilience knowledge to their company. Study A has identified a comprehensive group of concrete SSRES practices and embedded them into a holistic SSRES concept. The study additionally provides insight on the different adoption configuration and different practices in terms of governance and procurement object level. This study thereby contributes to their understanding of the components, constructs, and configurations of SSRES and its associated practices.

*M2* is dedicated to the difficulty of evaluating the effectiveness of SSRES practices. In general, buyers and supply managers from MCs face challenges when attempting to analyze how effective a practice is for their setting and their needs. Additionally, they do not know which KPIs to use to measure this effectiveness. Study B tackles these issues by (1) presenting an assignment of KPIs to specific SSRES practices and (2) presenting a method that measures the effectiveness of a SSRES practice with real-world data. The study thereby exemplifies effectiveness measurement beyond subjective evaluation. The high effort makes it unfeasible to make this assessment for each SSRES practice and thus reserves this undertaking for future research. The high effort of providing empirical data to measure the effectiveness of each SSRES practice in depth is beyond the scope of this dissertation. Instead, the study equips the practitioner with the tools to make an effectiveness estimation for a portfolio of SSRES practices.

*M3* addresses the difficulties of assessing the cost of SSRES practices. Purchasers and supply managers have no systematic way of determining how much the setup, maintenance, and usage of SSRES practices costs. Study C outlines a method based on activity-based costing, which acts as a guideline for the bottom-up estimation of expenditure on activities that pertain to SSRES practices. While these act as estimations act as estimations alone, they provide a solid foundation for determining the order of magnitude of expenditure and the distribution of associated resource pools. The expenditures can be easily aggregated up to higher-order constructs as presented in Study A.

The synthesis of the studies—RESPIRE—provides the practitioners from the buying organization of MCs with a holistic method to conduct SSRES self-assessments in terms of cost and effectiveness based on adopted practices and to receive bespoke recommendations for further development and exploration based on indicated contingency variables. Consequently, this research is highly practice-oriented and demonstrates the correspondence of research gaps of SSRES operationalization with those challenges faced by practitioners.

**Application of the developed resilience practice recommendation system**

The developed resilience practice recommendation system (RESPIRE) must be applied in practice to achieve an impact. This dissertation therefore proposes a blueprint on how CEAs on a portfolio of SSRES practices can be conducted. RESPIRE acts solely as a starting point, outlining a set of general guidelines to follow to conduct a CEA, with potential for individual adaptations based on the requirements of the industry. The outcome of RESPIRE differs significantly from company to company due to individual expenditures, effectiveness measurements, and provided contingency variables. Hence, it represents an ideal-typical guideline with the need for adaptation for the individual situation. For example, the choice of effectiveness measurement method (with/without principle) and the source of data (objective or subjective) should be chosen by the practitioner based on the available data and analysis capacities. Buyers should therefore not blindly follow the practice recommendations, but instead decide case-specifically whether the results are suitable.

MCs are currently experiencing a fundamental shift, as they must increasingly learn to adapt to an ever-changing environment with continuous preparedness for disruptions. So far, general confidence in the future allows for lean structures and processes, as well as long-term planning horizons (Ivanov & Dolgui, 2021a). Now, buyers must learn to live with short-term planning horizons with highly limited observability and controllability. They must adopt the mantra "I know only one thing: that I know nothing," to cite the Greek philosopher Socrates, implying high uncertainty and proportionally more frequent disruptive risks. While it does not guarantee full protection against disruptions, RESPIRE is a steppingstone to complement existing SCRM tools to allow for the management of upstream resilience.

## 6.3 Limitations and future research

While the present dissertation thoroughly examines the related research domains and is based on well-established theories, several limitations can be identified, as with all research. In the following, both content-related and methodology-related limitations are highlighted, after which several avenues for future research are outlined.

Limitations of this thesis' content are explained below and include (1) the generalized and integrative perspective on the research setting, (2) limited scope due to the chosen unit of observation, and (3) missing large-scale validation of the final model.

First, the present dissertation investigates the operationalization of SSRES based on derived managerial challenges (see Section 1.1) and theoretical shortcomings (see Section 1.2). In attempting to address these, this research investigated a broad scope at the intersection of large research areas, i.e., risk management, purchasing and supply management, and cost management. Therefore, this research resorts to a holistic and integrative perspective, leading to results that are adaptable for different MCs. This applies for all parts of dissertation in the results chapter (see Chapter 5). It is thus recommended that these results be interpreted as general guidance. A detailed adaptation and customization of the results to specific contexts could further reveal in-depth results.

Next, this research's unit of observation was constrained to MCs in Switzerland and Germany due to the geographic proximity and resulting similarity of company characteristics to provide a solid foundation for comparability. More concretely, MCs from this geographic area have similar characteristics in terms of geographic spread of suppliers. The results of this research must be interpreted as ideal-typical outcomes that must be further adapted to the company context.

Furthermore, this research is limited due to its partial use of qualitative research methods. While the approach closed the research gaps (see Section 6.1) and led to a systematic SSRES operationalization method (see Section 5.5), the results were not verified by large-scale surveys. Especially from a practitioner's point of view, this can be an undesirable circumstance given that decisions made based on a CEA on SSRES are based on hard facts such as individual practice costs. Particularly in the MEM industry, which is typically characterized by high procurement volumes with respect to the revenue, financial aspects are considered vital for decision-making.

From a *methodological* point of view, several limitations can be identified: (4) the limited number of interviews and cases, (5) the subjectiveness of the collected data, and (6) the lack of validation and application of the research result in practice.

Studies A and C made use of semi-structured interviews as a data collection and validation method. Study B used a set of semi-structured interviews with practitioners from the buying organization purely for validation purposes. Thus, the empirical validation is mainly of qualitative nature and with a limited sample of interviews. Naturally, generalizability with a small set of interviews is limited, although insight saturation was reached; no further interviewees from a buying organization were expected to enhance the findings of this research. Several practices and capabilities can be enforced only with the incentivization of or mutual collaboration with different stakeholders (e.g., supplier, logistics service provider, or public authority). Their capacities and requirements were indirectly represented through the interviewees from the buying organization. Therefore, the results are limited to the extent of not incorporating interviews with other stakeholder types in the analyzed data. Furthermore, the intentional geographic concentration of interviewees in Switzerland and Germany limits the validity of this study to this area. A different composition of interviews in different regions could therefore affect the results in certain parts. A cross-regional longitudinal study to enhance the geographic generalizability of the results and to reveal location-specific insights is therefore recommended.

With a reliance on the input of the practitioner, the resulting method is deeply affected by both data availability and data quality. Companies often do not have the documentation available to identify and evaluate all SSRES practices in terms of cost and effectiveness. The lack of data is often compensated with experience As Bromiley and Rau (2014) confirm, “the estimates of costs and benefits [of a practice] depend on managerial opinions with only modest empirical support” (Bromiley & Rau, 2014, p. 9). An exemplary source of subjective bias is the survivorship bias, in which overly optimistic reports about the effectiveness of practices are provided. This is the direct result of the discrepancy between actual versus perceived benefit of the individual practices. With the introduction of guiding KPIs, this bias is accounted for, but can never be fully excluded. Therefore, the risk of “garbage-in garbage-out” during the usage of the dissertation’s result, which indicates that flawed input results in suboptimal output, prevails. Practitioners involved in future studies must be therefore incentivized to collect the necessary cost and performance data and form their opinions based on evidence-based empiricism.

The overall explorative research approach included iterative validation of the results of this dissertation. The application of RESPIRE has been conducted with one company so far, however, a final validation of results would require multiple applications of the method in practice. Thus, this research calls for a large-scale validation study in the form of multiple case studies or consortium research. A potential validation study could aid in determining further mechanisms not identified in this research and optimize the operationalization concept to ensure its practicability in the real world. This dissertation may act as a foundation for practice-oriented future studies to expand the contributions of this research and make it suitable for real-world usage.

Three further avenues of research are suggested, all of which address the limitations of this study. First, the present research reveals that the operationalization of resilience, more specifically SSRES, needs to be deepened. As this dissertation is rooted in an integrative perspective and based on eclectic theoretical access to the research phenomenon, researchers can deepen this view with additional studies to better understand the temporal development of variables within the operationalization system and the cross-effects of variables within RESPIRE. For this purpose, the application of further theories may aid in better structuring and deeper understanding sub-phenomena revealed during the research process.

Furthermore, the integration of other stakeholder types could enrich the current data pool and help understand the dynamics of incentivization and collaboration to adopt SSRES practices. The capabilities of suppliers, logistics service providers, and public authorities could be additionally accounted for and pave the path toward a dyad view of SSRES operationalization. For this research avenue, the supply chain practice view could aid in determining the stakeholders and the associated resource distribution involved in the setup, maintenance, and usage of SSRES practices (C. R. Carter et al., 2017).

The final recommendation relates to the managerial impact and the influence of RESPIRE on managerial decisions in practice. While this research offers an operationalization approach for SSRES, it needs to be examined thoroughly in practice to see how it works in real-world settings and what lessons can be drawn from it. As a result, it is advised to undertake case study research using the proposed operationalization over a longer period of time to measure the effects of its recommendations.

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# Appendix

## Appendix A.[44] Enthoven, M.: Supply-side resilience: a practice-based view

*Presented in former version at:*

31st IPSERA Annual Meeting 'Building bridges', Jönköping, Sweden, 13 April 2022

[44] The presentation of the references in Appendix A corresponds to the guidelines of the target journal to which it has already been submitted.

# Appendix B.[45] Enthoven, M.: Measuring the effectiveness of supply-side resilience practices

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# Appendix C.[46] Enthoven, M.: Determining the cost of resilience: an activity-based costing approach for buyers

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[46] The presentation of the references in Appendix C corresponds to the guidelines of the target journal to which it has already been submitted.

# A Study A: Supply-side resilience: a practice-based view

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*This research examines supply-side resilience grounded in the practice-based view of firms. The purpose of this research is to provide insights for achieving resilience as a focal company by developing a conceptual model that maps the relationships between resilience practices, explanatory resilience constructs, and the influencing variables on these constructs. A systematic literature review reveals 135 supply chain resilience practices tied to different objectives, elements, capabilities, and strategies. A survey with 62 buyers and risk managers from buying manufacturing companies reveals that around two-thirds of supply chain resilience practices fall within the responsibility sphere of procurement. Finally, a multiple case study with six manufacturing companies identifies the practices currently adopted, along with adoption governance, adoption level, and an effort-effectiveness evaluation. While the company-contingent results differ from each other, the findings are relevant for testing a conceptual resilience model. Overall, the research strongly supports that while some resilience practices are imitable across companies, some require resources, experience, and market position as key contingency variables. Supply-side resilience can thus be seen as a contingency variable-moderated, continuously self-learning feedback loop to address disruptive upstream risks.*

Keywords: supply-side resilience, manufacturing company, practices, practice-based view, typology

## A.1 Introduction

Since the 1980s, the procurement function of manufacturing companies (MCs) has mainly prioritized low prices during the acquisition of raw materials and product parts, driving the trend toward high cost pressure for suppliers and outsourcing of production (Bremen et al., 2007). This inevitably led to reduced value creation depth of MCs and more complex and geographically distributed supply chains (SCs) (Alard et al., 2010). To deal with the risks that naturally emerge with this complexity, MCs adopted a series of supply chain risk management (SCRM) strategies and practices (Rao & Goldsby, 2009; Ritchie et al., 2008). However, unexpected supply disruptions such as Hurricane Katrina in 2005 (Vigdor, 2008), the Japanese earthquake in 2009 (Pettit et al., 2013), and the outbreak of SARS-CoV-2 in 2020/21 (Gray & Wynstra, 2020; Ivanov & Dolgui, 2021) have revealed the weaknesses of these practices, causing widespread production halts and high revenue losses among MCs (Simchi-Levi et al., 2014). The resulting damage had demonstrated that these events' suddenness and unpredictability could not be effectively dealt with by current practices, whose adoption, maintenance, and usage often relies on empirical data for events that have happened in the past (Knight et al., 2022; Pettit et al., 2010).

Meanwhile, supply chain resilience (SCRES) has become a topic of strategic importance for PSM to resist and recover from the impact of unexpected disruptions (Fiksel, 2015; Melnyk et al., 2014, 2021; Schuster et al., 2021). While the term resilience is often discussed in a biological and psychological context, SCRES intends to address those supply chain risks preceding unexpected disruptions, which SCRM ineffectively captures. Even though the causes of these risks may arise from anywhere, they occur primarily in the upstream SC and escalate downstream (Manuj & Mentzer, 2008; Nitsche & Durach, 2018). This makes a MC's interface with its upstream SC (i.e., the purchaser) decisive in managing these types of risks (Pereira et al., 2014). While research has introduced various theoretical constructs to build SCRES such as processes, enables, and elements, their respective relevance for purchasing and supply management (PSM) remains low. While few studies identify specific supply-side resilience (SSRES) constructs (Dabhilkar et al., 2016; Pereira et al., 2020), research generally lacks a concretization of practices and associated effort-effectiveness. Therefore, the following research questions will be investigated:

*RQ1*: How can SSRES be conceptualized?

The conceptualization of SSRES should act as groundwork for concretizing practical implications, especially for buyers of MCs. Concretization requires operational practices that can be customized according to their needs. The following research question is therefore asked:

*RQ2*: What are the SSRES practices of MCs?

Conceptualization can be complete only with the consideration of associated moderating and mediating variables and relationship of influence with SSRES constructs. These contingency variables could be structured and integrated into the existing concept. The third research question is therefore formulated as follows:

*RQ3*: What are the contingency variables relevant for the adoption of SSRES practices in MCs?

This research aims to systematize and integrate the theoretical constructs explaining SSRES, build a catalog of SSRES practices, and understand how these practices can be configured according to the requirements of the adopting company. Finally, the research aims to provide a first glimpse into an effort-effectiveness analysis for individual SSRES practices. The practice-based view (PBV) provides the theoretical underpinning to structure the concept and allows for an evaluation of the ease and effectiveness of adopted practices in specific cases.

This research is structured as follows: After a theoretical background on SCRES and its relevance for PSM in Section A.2, the three-stage research process is described, including a literature review, a survey, and expert interviews about the consequences of the outbreak of SARS-CoV-2 in Section A.3. Subsequently, the results from the study are presented in Section A.4. Theoretical and managerial implications are explored in Section A.5, before the limitations are demonstrated in Section A.6.

## A.2 Theoretical background

### A.2.1 Supply chain resilience vs. supply chain risk management

SCRM intends to reduce and mitigate specific and well-defined *operational* risks backed by probabilistic models (Pettit et al., 2010). However, the event-driven set of practices that SCRM entails reaches its limits when dealing with *disruptive* risks that occur with low probability and may have catastrophic consequences (Brusset & Teller, 2017; Christopher & Peck, 2004). These catastrophic consequences may take the form of a *disruption*, which can be either instantaneous with a quick recovery (e.g., terrorist attack) or characterized by gradual decline and recovery with structural effects on supply chains or even economies (e.g., a pandemic) (Ivanov, 2021). Either way, risk models that are driven by statistical tools such as Value at Risk (VaR), beta coefficients, and probability-impact scores lack empirical data for this type of events (Prakash et al., 2017).

SCRES can be seen as an event-agnostic concept complementary to traditional SCRM, which deals with high-impact, low-probability (HI/LP) risks in a more effective way (Pettit et al., 2010; 2013). While SCRM focuses on restoring or maintaining the previous performance after a specific disturbance occurs (i.e., a risk event is realized), SCRES includes the possibility of using the opportunity of disruption to move to a more desirable performance than before (Sheffi, 2005). SCRES can be generally defined as the capability of SCs to respond quickly to unexpected events to restore operations to the previous or a better performance level (Christopher & Peck, 2004). Nonetheless, SCRM and SCRES have a common bottom line: both intend to achieve a competitive advantage by adopting specific practices to address risks (Ali et al., 2017).

Multiple authors have identified and integrated constructs to streamline the understanding of SCRES (Ali et al., 2017; Christopher & Peck, 2004; Hohenstein et al., 2015). For example, Ali et al. (2017) breaks down the concept into three different SCRES strategies (proactive, concurrent, and reactive) to deal with the pre-, during- and post-phase of a disruption. Each of these strategies contains unique capabilities: the *capability to anticipate* a disruption as part of a proactive strategy, the *capability to respond* and *adapt* to a disruption as part of a concurrent strategy, and the *capability to recover* and *learn* from a disruption as part of a reactive strategy. These capabilities each include a set of SCRES elements (Christopher & Peck, 2004; Hohenstein et al., 2015), such as *situation awareness*, *flexibility*, and *contingency planning* (Blackhurst et al., 2005; Donadoni et al., 2018; Macdonald et al., 2018; Wieland & Durach, 2021). Moreover, managerial practices for each of the elements are identified. Examples for the mentioned practices are *sensing and interpreting events* (Christopher & Peck, 2004), *anticipation / preparedness to changes* (Durach et al., 2015), *velocity and acceleration* (Tang & Tomlin, 2008), and *supply chain reconfiguration* (Blackhurst et al., 2005).

Despite the efforts in qualitative literature to concretize the concept of SCRES with the help of managerial practices (Ali et al., 2017), it can still be an abstract concept to grasp due to its high subjection to company contingencies and environmental context (Enthoven et al., 2022). Therefore, authors have proposed explanatory performance metrics to operationalize the concept (Carvalho et al., 2011; Wu & Blackhurst, 2009; Zavala et al., 2018), such as lead time deviation (Carvalho et al., 2012), on-time delivery (Cavalcante et al., 2019; Ivanov, 2020), or sales volume (Ivanov et al., 2016). As the derivation of most metrics relies on simulated data and complex operations models, some counterefforts have recently been undertaken to integrate real-world data (Enthoven et al., 2022).

### A.2.2 Relevance of resilience in PSM

Van Weele and van Raaij (2014) posit that PSM "is concerned with the management of external resources – goods, services, capabilities, and knowledge – that are necessary for running, maintaining, and managing the primary and support processes of a company at the most favorable conditions." Over the past decades, PSM has developed into a business function of strategic importance that acts as an interface between a company's internal customers and the external upstream supply chain through planning, evaluating, implementing, and controlling strategic sourcing decisions (Essig et al., 2013). Its outward-facing nature is inherently tied to the responsibility to address risks that originate upstream in the supply chain and escalate downstream (Nitsche & Durach, 2018).

Today's supply networks are increasingly affected by environmental uncertainty (Ivanov & Sokolov, 2010), which includes more frequent supply disruptions and the emergence of "super disruptions" (Ivanov, 2021). Considering both the economic relevance of supply disruptions and the strategic importance of PSM as a link between the challenges and circumstances posed by the upstream supply chain and the focal company, it can be inferred that PSM plays a fundamental role in building and managing resilience (Pereira et al., 2020). Some research has been conducted on resilience in the context of PSM. After Pereira et al. (2014) transferred constructs from the general SCRES concept to the PSM setting through an extensive literature review, the term "supply-side resilience" (SSRES) was coined (Dabhilkar et al., 2016; Pereira et al., 2020), and will be used for the remainder of the study. SSRES can be defined as the capability of a buying company in developing effective practices to anticipate, adapt, respond, recover, and learn from a disruptive event originating in the upstream supply chain through adequate resource management (Ali et al., 2017; Brusset & Teller, 2017; Dabhilkar et al., 2016; Kamalahmadi & Parast, 2016; Pereira et al., 2020).

Several theoretical lenses have been used to investigate SSRES as a phenomenon. Some authors use the dynamic capabilities view (DCV) to theoretically underpin SSRES, a common tool to explain competitive advantage (Barreto, 2009). First, Dabhilkar (2016) characterizes SSRES as a set of four dynamic capabilities (proactive-internal, proactive-external, reactive-internal, and reactive-external), each consisting of practice bundles (Dabhilkar et al., 2016). Second, Pereira et al. (2020) examine buyer-supplier dyads and match those resilience practices mentioned in literature to those in expert interviews. After categorizing the practices into proactive and reactive, they conclude that the customization across three dimensions determines a SSRES strategy: nodes (e.g., pick-up points), edges (e.g., means of transport), and general conditions (e.g., toll systems). Third, Brusset and Teller (2017) see upstream resilience as a combination of resources and capabilities employed, combining DCV with the Resource-Based View (RBV).

Furthermore, some studies highlight the importance of PSM in building resilience but use no theoretical lens explicitly. For example, Melnyk et al. (2021) conduct a large-scale study to highlight the disadvantages of SMEs relative to corporations during a disruption, stressing the importance of company size when investigating SSRES. Moreover, Glas et al. (2021) use a medical analogy to compare the spreading, containment, and recovery from a virus to that of a supply disruption. Knight et al. (2022) urges researchers to borrow and adapt theoretical lenses from other fields to investigate PSM phenomena such as SSRES.

### A.2.3 Practice-based view

According to Bromiley & Rau (2016), the Resource-Based View (RBV) attempts to explain a company's sustainable competitive advantage "as stemming from firm resources that are rare, valuable, hard or impossible to imitate or duplicate, and hard to substitute" (Bromiley & Rau, 2016). The authors view RBV as flawed, since standard SC practices such as just-in-time principles or Kanban have empirically proven valuable and contribute to a competitive advantage. PBV, on the other hand, assumes that performance can be explained with a combination of imitable practices. A practice can be defined as "a defined activity or set of activities" with a specific objective (Bromiley & Rau, 2014, p.1249). While adopting some practices may negatively affect the company, PBV purports that the combination of the proper techniques coupled with a deep understanding of their respective performance implications explains a competitive advantage. This performance implication is ultimately understood as a company's profitability (Bromiley & Rau, 2016).

PBV aligns with SSRES, as it can be seen as a combination of *practices* with intermediary explanatory variables, namely *objectives*, *elements*, *capabilities*, and *strategy* (Ali et al., 2017). A preliminary framework using PBV's expanded model is developed to describe the relationship between variables within the SSRES concept from the perspective of the buying company (see Figure A-1).

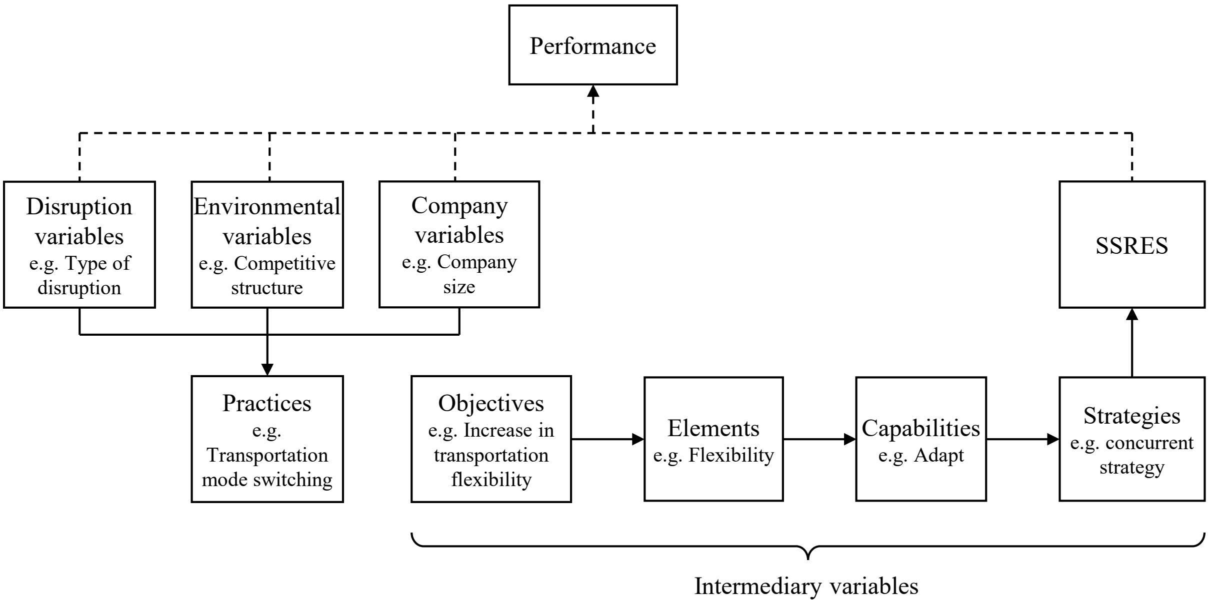


**Figure A-1.** The preliminary conceptual model of SSRES based on Bromiley & Rau's (2014) expanded PBV model

Several "practices", as dubbed in the literature, in fact describe an objective rather than a concrete set of activities. An example of this is "increase in cybersecurity" within the company (Pettit et al., 2013), while a concrete practice would be the adoption and usage of a multi-factor authentication system for a company's IT services. For this reason, the concept of *objectives* acting as a bridge between practices and elements was introduced. The elements, in turn, enforce specific capabilities, which fall into a proactive, concurrent, or reactive SSRES strategy. Finally, the combination of all three strategies makes up the SSRES at the company.

The adoption and practices is influenced by company contingency variables (e.g., company size, company location), environmental variables (e.g., competitive structure, regulations), and disruption variables (e.g., type of disruption, phase of disruption). Large and more established organizations adopt new practices earlier yet retain old practices longer (Nakamura & Ohashi, 2012). On the other hand, smaller and younger companies are more flexible and prone to adopt and abandon practices rapidly (Pierce & Delbecq, 1977). While Brusset & Teller (2017) find that "the size of the focal company […] has no influence on its resilience" (Brusset & Teller, 2017, p. 66), other authors remark that larger companies have more sophisticated tools and are thus better equipped to address external risks (Melnyk et al., 2021; Ozdemir et al., 2022). Regarding environmental variables, the state of SSRES at competing companies may influence the adoption strategy of practices at the focus company. In addition, different phases of disruption influence decisions regarding practice type adoption and usage. A post-disruption phase might lead the buying company to adopt more practices that fall into the reactive strategy.

For this purpose, the contingency theory (CT) can be applied. This theory posits that organizational effectiveness results from fitting company properties to contingencies, including environment, organizational size, and organizational strategy (Donaldson, 2001). CT demands that companies adapt themselves to new levels of contingencies over time in order to maintain their performance (Tate et al., 2022). While applied in risk management (Mikes & Kaplan, 2013), the theory offers potential insight on structuring and integrating the contextual variables that influence the adoption and usage of SSRES practices, and thus the operationalization of SSRES.

In general, SSRES impacts both the short-term and long-term performance of a company, before, during, and after the disruption, which can make the difference to a competitive advantage. The adoption of many practices requires a high level of investments, driving down the pre-disruption profit (Pettit et al., 2013). When practices are implemented when a disruption hits, however, the practice portfolio may contain company damage and the competition may suffer. Thus, SSRES interacts with company contingency variables, environmental variables, and disruption variables.

## A.3 Methodology

The study follows a three-stage abductive research approach with the practice-based view (PBV) as a theoretical underpinning. While Stage 1 deductively identifies SCRES practices through a literature review, Stage 2 transfers these practices into the setting of PSM through a survey. Finally, Stage 3 investigates SSRES practices in detail in six cases. In the following, the stages will be described in detail. A funnel-like explorative research setting was selected due to the lack of empirical research on this topic (see Figure A-2). A combination of qualitative and quantitative research to study SSRES is selected (Goldsby & Zinn, 2018).

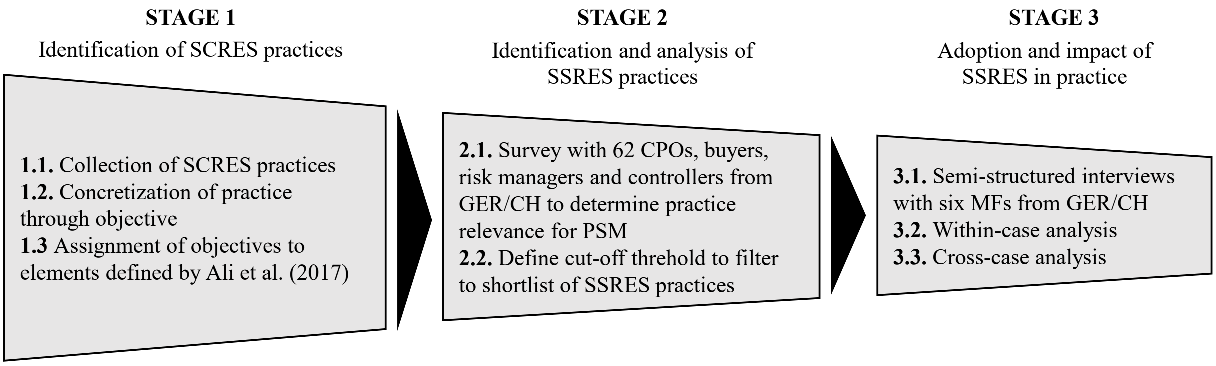


**Figure A-2.** Three-stage abductive research approach

In *Stage 1*, a literature review was conducted to collect SCRES practices and a respective categorization into the framework of PBV. A database search was conducted on Scopus and Web of Science for a period of 22 years (2000-2021). This period was chosen because the first appearance of SCRES literature arises in the mid-2000 (Pereira et al., 2014). The selection of the papers was made through search strings relating to SC resilience itself, PSM, and buyer-supplier dyads. Papers were screened according to title and abstract. Afterward, a more in-depth reading of the introduction and conclusion and the quality assessment was the final criteria for searching concrete resilience practices used, mentioned, and analyzed.

A narrow interpretation of Bromiley & Rau (2014)'s practice definition was taken in order to judge whether an object was a practice, i.e., the ability to break down the object into setup activities and recurring activities (e.g., *alternative backup transportation method*). If the object was too abstract to break into concrete activities, the candidate in question was categorized as an objective (e.g., *increase in transportation flexibility*). After identifying the practices and their associated objectives, both were assigned to the SCRES elements as defined by Ali et al. (2017). Objectives were matched to elements through codes synonymous to the element, or the objective mentioned the element itself (e.g., the objective *increase in transportation flexibility* is allocated to the element *flexibility*).

In *Stage 2*, the objective was to determine the PSM relevance of the collected SCRES practices. With *PSM relevance*, the extent to which the practice falls within the responsibility sphere of the buyer is implied. The current lack of robust, empirical research on SSRES practices led the researcher to utilize a survey to explore the delimitation of SCRES resilience in the PSM setting. For this purpose, a small-scale survey with 62 buyers from Swiss and German MCs was conducted. While the rather small survey sample allows for the generalization of a problem only in a limited manner, it also serves the purpose of framing the problem (Goldsby & Zinn, 2018; van Hoek, 2021). The PSM relevance of each collected practice was evaluated on a Likert scale (from 1 = irrelevant to 5 = highly relevant). All practices with an average score below 3 were deemed irrelevant and excluded from further investigation. The survey format was online and communicated via email.

In *Stage 3*, a series of semi-structured interviews with the respective CPOs of six selected German and Swiss MCs was conducted. While all MCs are headquartered in Germany and Switzerland and can be allocated to the MEM (machine, electronics, and metals) industries, their products, supplier portfolios, PSM processes and structures widely differ. The list of the anonymized interview partners and their associated company characteristics is provided in Table A-1. The MCs have a broad range of procurement volumes (PV) (CHF 9 million to CHF 2.23 billion[47]) and different ages (33 to 170 years). The company age and PV are proportional in this sample. On average, the firms have a PV of ~42% of the respective revenues, typical for MCs in the MEM industry[48]. This highlights the importance of the PSM function and the pressure for purchasers to make economically sound decisions to safeguard the MCs' competitiveness (Ellram & Carr, 1994).

**Table A-1.** Interviewees from the German and Swiss MEM industries

| **Acronym** | **Industry** | **Position** | **PV** (kCHF) | **Age** |
|---|---|---|---|---|
| A | Engineering | CPO | 9 | 45 |
| B | Electronics | CPO | 93 | 62 |
| C | Automotive | Head of purchasing | 230 | 84 |

[47] At the time of writing: CHF 1 ≈ USD 1

[48] Due to anonymity reasons, the respective company revenues are not indicated.

| | | | | |
|---|---|---|---|---|
| D | Engineering | Risk manager | 2,230 | 170 |
| E | Automotive | Assistant buyer | 1,400 | 94 |
| F | Chemicals | Risk manager | 13 | 33 |

The objective of this stage was to determine (1) the SSRES practices currently adopted in the individual company, (2) their respective level and context of adoption, as well as (3) their respective ease of adoption and effectiveness of usage during a disruption. For this purpose, a typology across three categories, i.e., adoption governance (AG), adoption level (AL), and evaluation (E), is used to categorize and judge the individual practices (see Figure A-3).

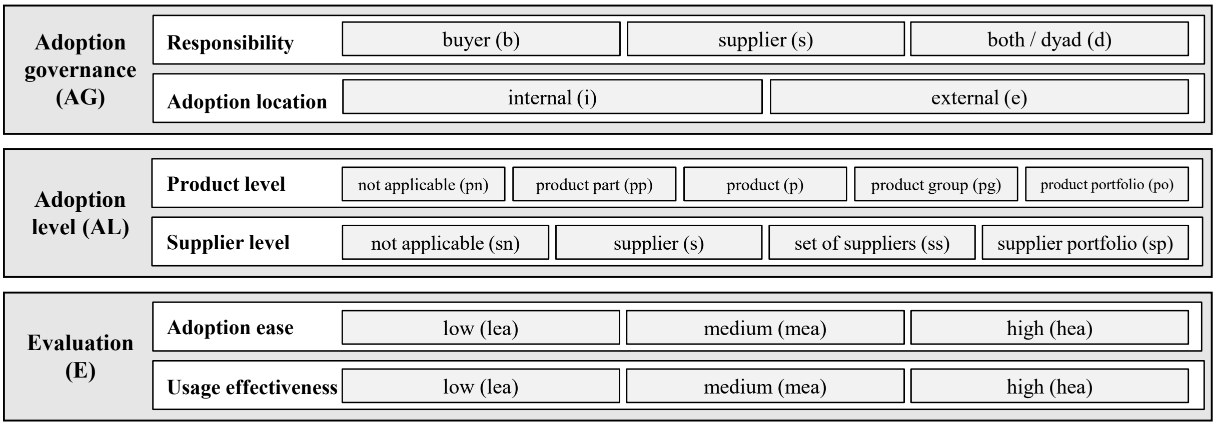

**Figure A-3.** SSRES practice typology for adoption context and evaluation

In the first category, AG, it was essential to clarify the responsible party for the practice adoption, i.e., the buyer (AG-b), the supplier (AG-s), or both in the dyad (AG-d). Furthermore, the adoption level indicates where and how a practice is adopted. The practice could either be adopted company-internally (AL-i) or with an external party (AL-e) such as the supplier or logistics service provider. Additionally, a practice could be adopted on different product aggregations; it may relate to a specific product part (AL-pp), a product (AL-p), a product group (AL-pg), the entire product portfolio (AL-po), or none of the previous (AL-pn). Similarly, a practice can be adopted to target a supplier (AL-s), a specific set of suppliers (AL-ss), the total supplier portfolio (AL-sp), or can be not particular to any of these levels (AL-sn). In the third category, the adoption ease, as well as the perceived overall effectiveness of the practice on SSRES from the CPO's perspective, are divided into three levels (low ease = lea, medium ease = mea, high ease = hea and low effectiveness = lef, medium effectiveness = mef, high effectiveness = hef), respectively, providing a first glimpse into a cost-benefit analysis regarding specific practices. The adoption ease can be judged based on the ease of usage: (a) the simplicity of the interface to the practice, (b) the modularity or “decomposability”, and (c) how well-defined the practice is (Bromiley & Rau, 2016). The interviews were transcribed and extracted practices were matched to the SSRES catalog with the respective adoption typology. A within-case analysis followed by a cross-case analysis aided in deriving both theoretical implications for the conceptual model and practical implications regarding the status quo of SSRES in German and Swiss MCs.

## A.4 Results

### A.4.1 SCRES practices

Stage 1 of the research process resulted in a catalog of 179 unique SCRES practice candidates from a total of 27 screened papers. Several duplicates could be identified, such as “early warning system” / “strong and weak warning signals” and “supplier risk monitoring system” / “supplier risk notification system”. After a second pass filtering duplicates and applying the practice definition of Bromiley & Rau (2014), a shortlist of 134 practices tied to 58 unique objectives were identified. These were allocated to 13 SCRES elements, 5 capabilities, and 3 strategies (Ali et al., 2017). Amongst other sources, practices were extracted mainly from Ali et al. (2017), Blackhurst et al. (2005, 2011), Christopher & Peck (2004), Karl et al. (2018), Macdonald et al. (2018), Macdonald & Corsi (2013), Melnyk et al. (2014, 2021), Peck (2016), Pereira et al. (2014, 2020), Pettit et al. (2010, 2013), Tang (2006), Tang (2006), Tang & Tomlin (2008), Wu et al. (2007), and Wu & Blackhurst (2009). While 87 (~65%) of practices could be allocated toward proactive SCRES, 32 (~24%) belong to concurrent and 16 (~12%) to reactive SCRES.

The quantity of proactive practices surpasses the concurrent and reactive strategies by far. However, the quantity is not an indicator of the effectiveness of the individual practices. The bias can be rather attributed to the established field of supply chain risk management, which tends to describe practices to proactively address risks, versus disruption or disaster management, which is concerned with the concurrent and reactive damage containment and recovery of an existing disturbance.

### A.4.2 SSRES practices

Stage 2 explored the relevance of the identified SCRES practices for PSM. The survey was sent out to 122 procurement managers and buyers in Switzerland and Germany from all industries and was ultimately filled out by 62 participants, who, on average, each indicated the relevance of 126 SCRES practices (~93%) for PSM. Thus, each practice was evaluated 58 times on average, with a maximum of 93 times and a minimum of 23 times. The full chart of indicated relevance for each practice categorized into the individual SCRES elements is found in Figure A-4 (a tabular view is provided in Table A-2, Appendix Section A.8.3). With the lower relevance threshold at 3 out of 5, 65 of 135 (~48%) practices that fall into the category of SSRES.

From those 65 practices, 35 (~54%) are *proactive*, 22 (~34%) *concurrent*, and 8 (~12%) *reactive*. These practices are classified as SSRES practices. The most SSRES practices can be found within the capability *anticipate* (35), followed by *adapt* (15)*, respond* (7), *learn* (5), and finally, *recover* (3). Breaking the capabilities down into elements, the most practices can be found within *flexibility* (10), *robustness*, (9), *knowledge management (pre-disruption)* (8), *situation awareness* (7), *visibility* (6), *security* (5), *redundancy* (5), *collaboration* (5), *knowledge management (post-disruption)* (3), *agility* (2), *market position* (2), *building social capital* (2), *contingency planning* (1). Further breaking down the elements, the top five objectives are *increase in preparedness* (8), *improved information technology or information sharing* (5), *increase in supplier risk management* (5), *decrease of financial risk* (5), and *improvement of supplier loyalty* (5). A full overview of the breakdown from strategies to the objectives is found in the Appendix, Figure A-9.

### A.4.3 Within-case analysis

Finally, Stage 3 is dedicated to the company-specific case studies. A selection of 43 from 65 unique adopted SSRES practices for their respective typologies could be identified for all companies, i.e., 7 for A, 8 for B, 14 for C, 25 for D, 14 for E and 7 for F (counting duplicates). From the 43 unique practices adopted, most belong to proactive SSRES (26) and concurrent SSRES (13), while reactive practices were the least adopted (4). In the following, company-specific results will be highlighted.

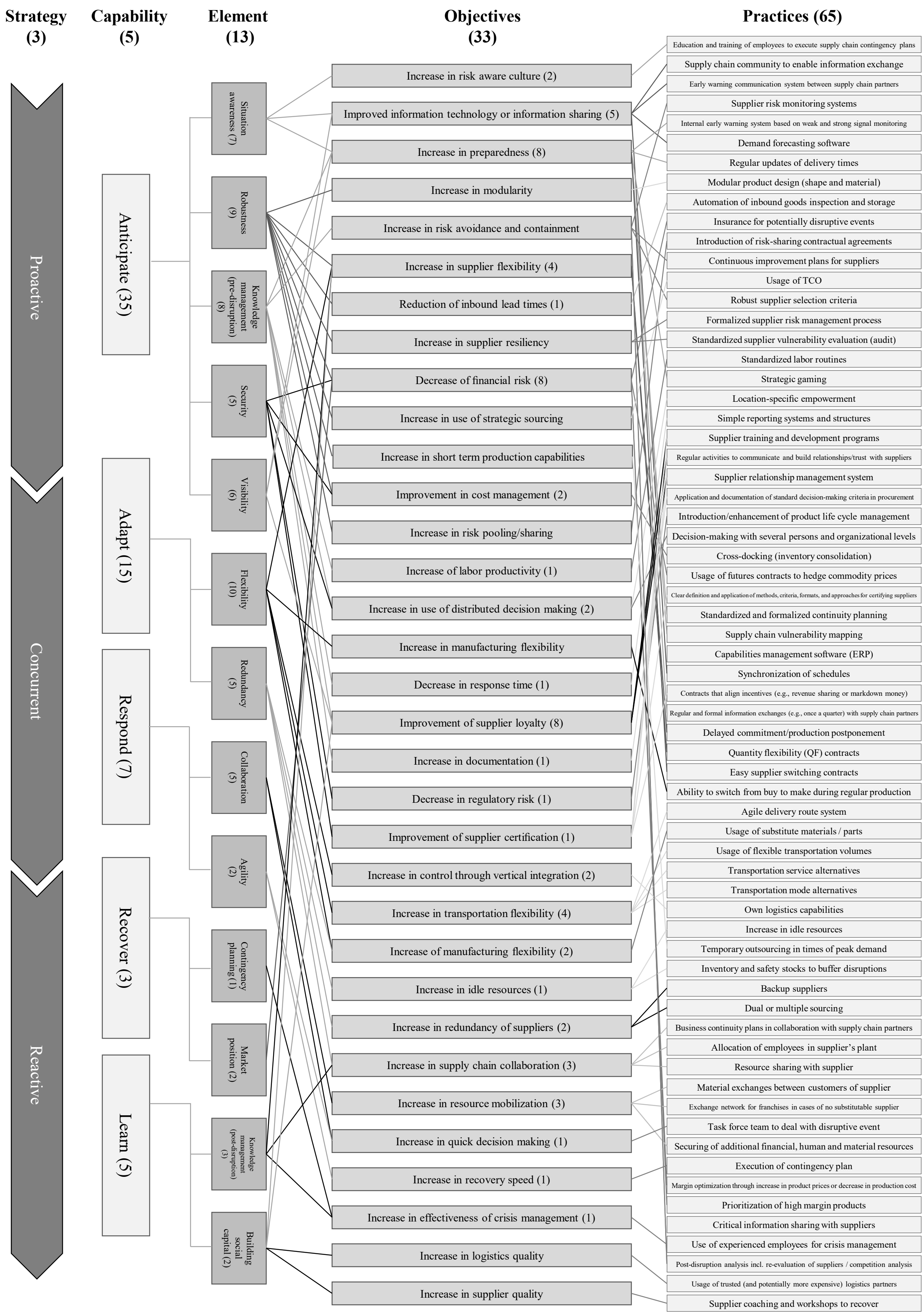


**Figure A-4.** Construct breakdown from strategies to practices

Company A, the smallest of the six in terms of revenue and PV, has adopted two proactive practices (#19 and #24), four concurrent practices (#28, #34, #35, and #36), and one reactive practice (#41). According to the CPO, the company "never had a major disruption. However, [last year we] needed to improvise to deal with supply shortages quickly." This confirms the high focus on concurrent practices, indicating that certain ad-hoc decisions were made to contain the damage (especially redundancy). Most adopted practices were product- and supplier-specific, i.e., SSRES practices were adopted especially for critical products that had to be prioritized in case of a disruption. For example, the company rapidly switched from buy to make when a supplier was not delivering anymore (#28). All practices were adopted internally (AL-i), and more than half of them were product-specific (AL-p) (~57%).

Similar to Company A, Company B set its focus on proactive and concurrent practices. Noticeable was the concentration of practices in the category "robustness", which included creating risk-sharing contractual agreements (#10), developing continuous improvement programs for suppliers (#11), and the application of robust supplier selection/evaluation criteria (#13). According to the CPO, these practices required regular maintenance and iterative optimization, which takes up company resources. Additionally, individual practices within the concurrent SSRES category were identified. This included product-specific practices (AL-p), i.e., evaluating and introducing transportation alternatives (#31). Dual sourcing (#36) was used primarily for critical product parts. Various product and supplier configurations were used for the adoption with a slight preference for internally adopted practices. The CPO added that the company "had supply shortages of critical parts in 2009 due to bankruptcies of our suppliers, that is why we were better prepared this time." This highlights the importance of experience when dealing with uncertainty.

As a larger company in revenue and PV compared to Companies A and B, Company C has adopted more SSRES practices in terms of quantity. It adopted nine proactive practices (#2, #5, #6, #13, #17, #20, #23, #24, and #26) with a focus on situation awareness, four concurrent practices (#29, #30, #36, and #38), and one reactive practice (#40). Around 75% of all practices have been adopted internally (AL-i), 45% have been adopted on a product group level, and 50% on supplier set levels. Few practices are specifically designed for product parts (P29) or single suppliers (#26, #29, #30, and #36).

As the largest company interviewed in terms of revenue and PV, Company D adopted 16 proactive SSRES practices (#1, #3, #7, #9, #11, #13, #14, #15, #16, #18, #19, #20, #21, #24, #25 and #26). Practices from all elements (situation awareness, robustness, contingency planning, knowledge management, safety, and visibility) are present. In addition, six concurrent SSRES practices (#33, #35, #36, #37, #38 and #39) and three reactive SSRES practices (#40, #41 and #42) were implemented. Redundancy is the focus for the concurrent strategy, while market position is the focus for the reactive strategy. The risk manager commented “we made sure we had a little extra of everything” (Risk manager, Company D). Company D was the only one of the six companies studied to implement more than one reactive practice.

Company E was the second largest of the companies to implement eight proactive SSRES practices (#4, #8, #12, #13, #14, #19, #20 and #22). The focus in proactive practices is on robustness (#8, #12, #13 and #14). In addition, five concurrent SSRES practices (#27, #29, #32, #35 and #36) were adopted. Unlike Company D, concurrent practices of the flexibility element are embedded. Thus, the same number of concurrent SSRES practices were implemented as in Company D, but only half of the proactive SSRES practices. In addition, one reactive SSRES practice (#43) was implemented.

Company F, which is similar in size to Company A adopted three proactive (#4, #11 and #14), three concurrent (#35, #36 and #39), and one reactive SSRES practice (#40). While two of the proactive practices relate to robustness, the focus of two of the concurrent practices is on redundancy. Figure A-5 illustrates the number of adopted SSRES practices for the six companies, broken down by proactive, concurrent, and reactive strategies.

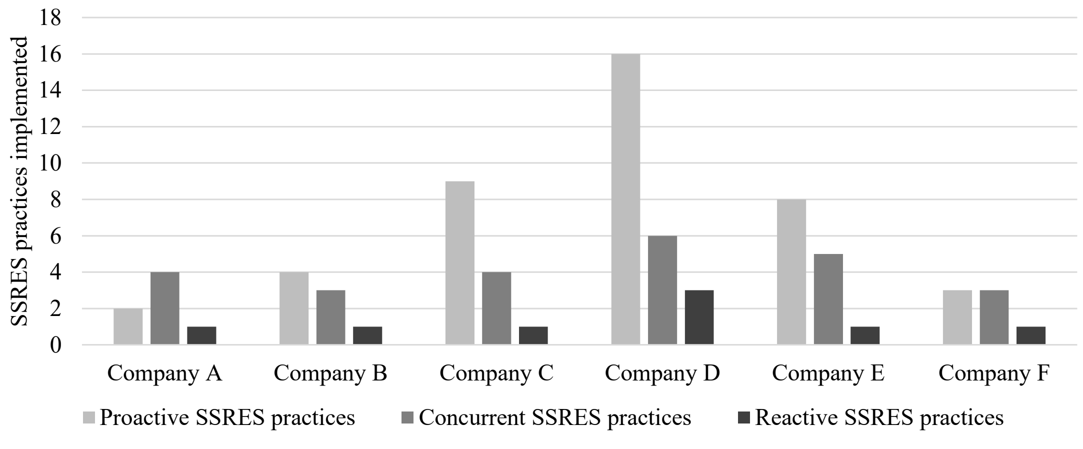


**Figure A-5.** Number of proactive, concurrent, and reactive SSRES practices implemented per company

### A.4.4 Cross-case analysis

In the following section, the evaluation of the practices in terms of adoption ease and effectiveness is presented in a cross-case analysis. To make sense of these results, the adopted SSRES are illustrated in a matrix spanning the adoption ease and the effectiveness of the practice into the three different strategies of SSRES: proactive strategy (see Figure A-7 in Appendix, Section A.8.3), concurrent strategy (see Figure A-8 in Appendix, Section A.8.3), and reactive strategy (see Figure A-9 in Appendix, Section A.8.3). The practice evaluation is subdivided into four categories. The *no-go* area is designated for those practices where either ease is less than high and effectiveness is low, or ease is low, and effectiveness is less than high. The *balanced* area contains those practices across the diagonal of the matrix (hea/lef, mea/mef, lea/hef). *Favorable* practices are those where ease is medium, and effectiveness is high (mea/hef), or ease is high, and effectiveness is medium (hea/mef). Finally, the *very favorable* area contains those practices with high ease and effectiveness (hea/hef). In the following section, we interpret the allocation of the practices to the individual categories.

First, no company adopted practices with low effectiveness except for Company C (#17) and Company D (#21). This overall optimism may be subject to survivorship bias (Brown et al., 1992), as the interview partners may systematically exclude failed practices. Second, it is noticeable that none of the reactive practices were evaluated as *very favorable*. Evaluations may be negatively biased as the disruption has already negatively impacted the company and the practice was adopted mainly to recover and learn. From the given data, it is generally unclear how fast or steep the recovery would have been without the practice. Third, none of the externally adopted practices (#5, #10, #11, #17, #32, #38, and #42) were categorized with high adoption ease. This is due to high coordination efforts when collaborating with suppliers to adopt new processes or structures (Wieland & Wallenburg, 2013). A direct proportionality can be observed between company revenue and the number of externally adopted practices, suggesting they have a more robust market position to incentivize their suppliers to agree to, e.g., collaborating on providing updates on disruption in a shared database (#1). Fourth, the results demonstrate that, in general, product- and product part-specific practices are easier to adopt than product group-specific ones. This is due to the higher precision and more targeted adoption approach, and generally requires less broad coordination to adopt. However, adopting a practice for a product part that is difficult to find can require deep coordination due to the high specificity. For example, #13 (“robust supplier selection/evaluation criteria”) has been evaluated as hae/hef. This is confirmed by Bromiley & Rau (2016).

For example, three of the six companies have categorized #36 (“Usage of dual or multiple sourcing”) as “very favorable”, all adopted with the same configuration (internal / product/supplier). On the other hand, #24 (“Clear definition and application of methods, criteria, formats, and approaches for certifying suppliers”) has been adopted by four companies but categorized differently (A as lea/mef, B as mea/mef, C as mea/hef and D as lea/hef).

## A.5 Discussion

In this section, the results of this study are discussed, and implications for theory and practice are derived. In general, it is demonstrated that the practices to support and bolster SCRES are scattered in literature and often represent tactical objectives rather than well-defined and concrete practices. By introducing SSRES objectives, the study proposes a slight modification of the current structuring of the term SSRES to break it down to an operational level through PBV.

The cases reveal some insights on the SSRES of German and Swiss MCs in the MEM industry yet pose some limitations for SSRES research. As all practices adopted in the companies are also mentioned in the literature, which confirms the validity of the proposed SSRES practice catalog. The adoption typology aids practitioners in assessing the context of the practices and a cross-product or cross-supplier evaluation of their SSRES. The results generally support the view that SSRES is a practice-based concept, as the individual composition of the various practices influences company performance. Nonetheless, three main company-internal contingency variables could be derived from the results, which influence the practice adoption and usage. CT aids in understanding the effect of these variables.

*Experience***.** Younger and therefore less experienced MCs struggle to devise and execute a systematic SSRES strategy. This is partly due to the lack of experience with disruptions. PBV must be thus seen as a cycle, as it provides a snapshot in time and does not consider the evolutionary aspect of SSRES initially, i.e., how practices are adopted and abandoned and in which context (Pereira et al., 2020). The capability to learn from experience or transferred knowledge about a disruption is crucial. Therefore, these findings can be partially underpinned by the knowledge-based view, which sees competitive advantage through experience (Grant, 1996).

*Resources*. MCs often struggle to adopt a balanced SSRES practice portfolio due to a lack of investment capacity. Smaller MCs are more likely to adopt practices requiring minor change and disruption to the organization in terms of processes, structure, and culture (Bromiley & Rau, 2016). Those with more resources were able to adopt more practices, as the results demonstrated. For example, Company D was able to acquire "a little extra of everything" in terms of safety stock and backup suppliers (Risk manager, Company D). This implies that practices require resources, and some are not imitable for all companies. In this regard, PBV thus reaches its limits and should take into account the resources as a contingency variable to adopt practices. RBV could explain this variable as it detects the inimitability of resources as a source of competitive advantage (Kraaijenbrink et al., 2009). Regarding the comments of Brusset & Teller (2017) that company size has no influence on its resilience, this research tends to agree, however, company size is an indicator for the resources deployable to adopt SSRES practices. This research argues that SSRES has an effect on company size, which consequently has an effect on what type of practices are adopted, maintained, and used which ultimately bolster SSRES.

*Market position*. The more established MCs have more frequently adopted practices beyond company boundaries (AL-e). This may be mainly due to their strong market position to incentivize their suppliers to cooperate (Christopher & Peck, 2004; Pettit et al., 2010). Notwithstanding, their adoption ease is mostly perceived as low, as larger companies have more complexity and a higher number of processes (Melnyk et al., 2021). However, as mentioned before, larger MCs have the resources to adapt. This supports the market-based view, which sees market conditions as the decisive force for performance differences among companies (Caves & Porter, 1977).

Furthermore, external contingency variables regarding the environment and the type of disruption were identified.

*Market competition.* Going hand in hand with the market position of the company, environmental variables such as market competition play an essential role in SSRES. Several authors argue that resilience has the ultimate goal of creating a sustainable competitive advantage (Ali et al., 2017), where the balance of profit erosion through practice investments and risk exposure through lean structures and processes must be found (Pettit et al., 2010, 2013). SSRES has an indirect influence on the market position, as it determines the performance of the focal company before, during, and after a disruption based on the expenditure and effectiveness of their practice portfolios. The market competition cannot be analyzed in this research due to lack of data and transparency into the competitive structure. This will be up to future research endeavors.

*Disruption type.* In general, two types of disruptions can be distinguished. While instantaneous disruptions describe sudden cycles of downturn and quick recovery caused by a single disturbance on a single supply chain tier, super disruptions describe the consequence of disturbance cascades across multiple supply chain tiers. The disruption type has an influence on the SSRES practices in terms of their effectiveness. Therefore, practitioners must adapt their practice portfolio according to their resilience time horizon.

Figure A-6 shows the resulting framework complemented by the results of the company cases. The SSRES mainly influences the three aforementioned variables “experience”, “resources” and “market position” via a self-learning feedback loop. Thereby, SSRES has a direct influence on experience, while it only has an indirect influence on resources and market position. This circumstance results from the fact that more resources are available as a result of better overcoming disruptions than without the corresponding SSRES. The market position is also strengthened by the fact that the company overcomes disruptions better than companies with poorer SSRES. We therefore offer a revised definition of SSRES: *It can be defined as the state of a focal company to deal with disruptive risks originating in the upstream supply chain and escalating downstream. This state is fed by a dynamic feedback loop primarily driven by a set of practices tied to specific objectives that enhance the capabilities of anticipating, adapting, and responding to as well as recovering and learning from the disruption occurring as a consequence of these risks. The adoption, maintenance, and usage of these practices are influenced by company size, market position, and experience as well as disruption and environment-specific variables.*

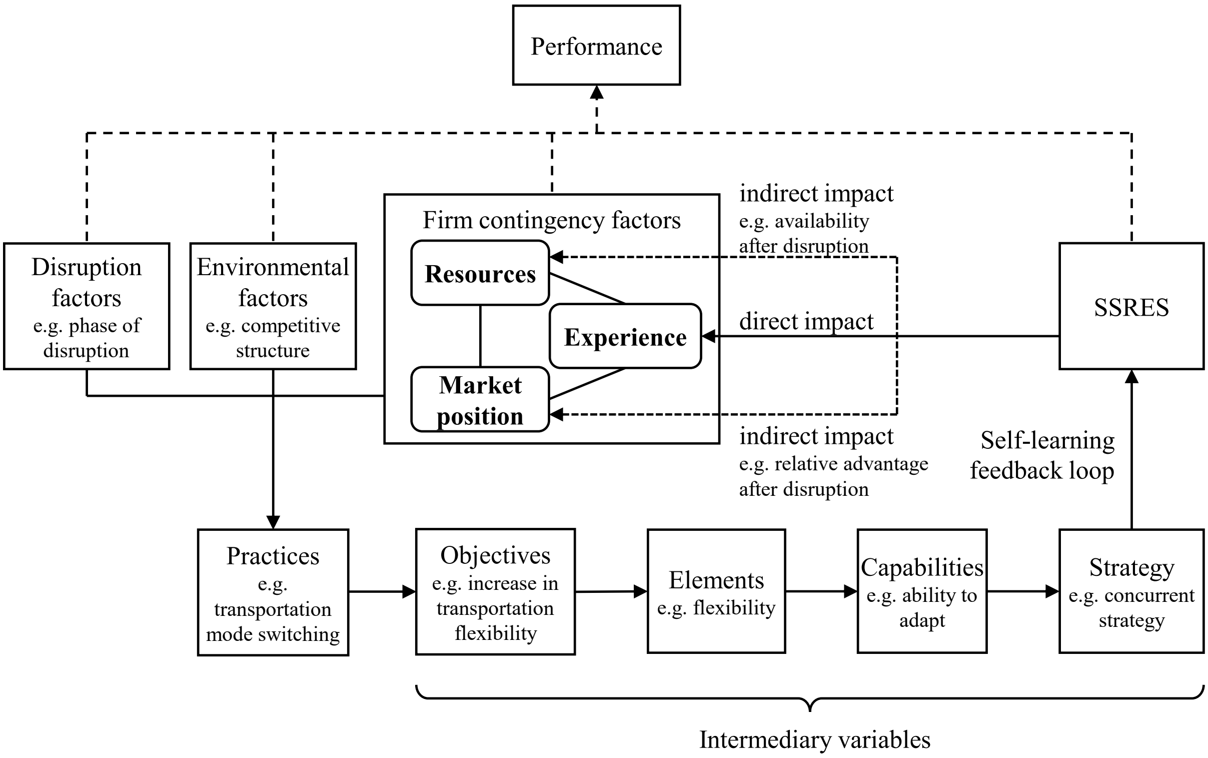


**Figure A-6.** The final conceptual model of a practice-based SSRES

The final conceptual model reveals that resources as a company contingency play a key role in building and managing SSRES. While some of the practices adopted are imitable across MCs of any size, others are not due to the limited investment capacity of smaller companies. Therefore, RBV is only partially valid in this case. Furthermore, RBV measures a sustainable competitive advantage, while PBV measures performance. As a cross-industry study does not allow competitive analyses, RBV could not be applied fully due to the inhibited ability to differentiate between performance and advantage (Bromiley & Rau, 2014).

Furthermore, our critique on the usage of DCV lies in the observation; as evaluated in the results, it is generally challenging to determine how much damage would have been mitigated or how fast a recovery would have occurred without a specific practice. For correct usage of DCV, independent snapshots before and after the disruption would be necessary. The missing snapshot can be generally constructed with scenario analysis or simulation, which requires inherently statistically inaccurate assumptions. While the view that the practices and resulting capabilities dynamically adjust with every new disruption in the feedback loop is valid, challenges in the application of DCV due to the lack of data can occur.

## A.6 Conclusion, limitations, and outlook

The contribution of this study is threefold. Regarding RQ1, the study has conceptualized SSRES grounded in PBV and identified associated constructs and their interrelationships. The research offers a revised definition of SSRES, describing it as a state describing how well a focal company can deal with disruptive risks originating in the upstream supply chain and escalating downstream, creating a hierarchy of higher-order and lower-order constructs embedded in a self-learning feedback loop. Regarding RQ2, SCRES practices are systematically gathered and structured to derive operational activities from each practice. This research has identified 135 practices and 88 subelements and assigned them to 13 SCRES elements. Therefore, the current SCRES literature is complemented as the practices mentioned represent concrete and well-defined activities. The study consolidates the concept of SSRES, a combination of those SCRES practices highly relevant for PSM managers. It is determined through a survey with CPOs that around two-thirds of mentioned SCRES practices are suitable for the PSM function, confirming the validity of PSM for securing resilience both within and outside the organization. Regarding RQ3, the adoption configurations of SSRES practice adoption by German and Swiss MCs in the MEM industry are analyzed. These configurations have implications for specific contingency variables, which play a role in the adoption, maintenance, and usage of SSRES practices. Finally, by evaluating the ease of adoption and the effectiveness with PBV as a theoretical underpinning, the study provides a first glimpse into operationalizing SSRES for practitioners.

The study demonstrates that MCs in Switzerland adopt SSRES practices. However, these companies rely less on structured SSRES practices but instead focus on situational, impromptu decision-making with practices that have the most minor adoption difficulty. Only companies with a solid market position can incentivize network partners to adopt practices. While they are usually more difficult to adopt due to high coordination efforts, they can be highly effective. Practices are equally challenging to adopt when applied to product groups (due to their broadness) and product parts (due to their specificity). Finally, the experience with past disruptions, the current investment capacity, and the market position have a decisive impact on how many and how broad SSRES practices are adopted.

As with all research, this study has some limitations. Due to the number of survey participants and constraints to the geographical region of Switzerland and Germany, the generalization power is limited. While the selection of interview partners was location-specific to constrain contingency variables and provide comparability, either a cross-company comparison with other sectors or a same-sector comparison with other regions could provide further insights.

Furthermore, it has been assumed throughout this research that one practice can be injectively allocated to one objective. In other words, while multiple practices could be tied to one objective, one practice could not be tied to multiple objectives. In practice, this is not always the case. Potentially, the breakdown of practices into activities and the effect analysis of associated activity processes may be a step toward addressing this.

In this research, it has been additionally assumed that the practices are independent variables and are not multicollinear. While multicollinearity affects the coefficients and p-values of a statistical model, it does not influence the prediction or precision of predictions (Farrar & Glauber, 1967). Therefore, an analysis of multicollinearity may be relevant in practice, however, a quantitative method from which both mutually reinforcing as well as mutually diminishing practices could be identified would be necessary. For example, P21 ("Decision-making with several persons and organizational levels") and P39 ("Task force team to deal with disruptive event") can be seen as mutually diminishing, as the former fosters decentralized decision-making, while the latter fosters quick decision-making. This creates a tension between distribution in a proactive SSRES strategy and speed in a concurrent SSRES strategy.

In this study, subjective and qualitative a posteriori evaluation metrics are used to measure the impact due to the difficulty of estimating how much damage prevention a specific practice caused. In general, the effectiveness evaluations in Stage 3 are subject to survivorship bias (Brown et al., 1992), since all practices have been evaluated to have at least a medium effectiveness. This may be an overly optimistic report, as the abandoned or low-effectiveness practices may remain unmentioned in the interviews. Notwithstanding, a priori estimations before practice adoption pose similar challenges as "the estimates of costs and benefits [of a practice] depend on managerial opinions with only modest empirical support" (Bromiley & Rau, 2016). Therefore, a future study that focuses on rigorous effectiveness measurement must be conducted.

Moreover, this study has focused more on perceived effectiveness than actual effectiveness in terms of monetary metrics (Aldrighetti et al., 2021). Thus, the self-evaluation of SSRES practice adoption is subject to additional bias. A more in-depth study of perceived vs. actual benefits regarding damage reduction and investment would be a logical next step. In the future, a study to identify the real benefit through monetary operationalization on the adoption of individual SSRES metrics is intended to identify the worth of these investments in case a disruption claims redundancies and flexibilities imposed by SSRES practices. Therefore, qualitative data could be complemented by process and cost data, reflecting a practice's encompassing activities.

Finally, Carter et al. (2017) propose the Supply Chain Practice View (SCPV), which extends PBV by the dimension of organizational level of analysis. As most AL-e practices entail a transaction of resources, practice adoption could be seen from an interorganizational point of view. However, this study focuses mainly on the responsibility sphere of the buyer and refrains from a dyad view. In the future, the dyad view should be considered to create a more complete picture.

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# A.8 Appendix

## A.8.1 SSRES practice catalog

**Table A-2.** Catalog of collected SSRES practices (only adopted practices contain an ID)

| ID | Strategy | Capability | Element | Objective | Practice | PSM Score |
|---|---|---|---|---|---|---|
| 1 | Proactive | Anticipate | Situation awareness | Increase in risk awareness | Education and training of employees to execute supply chain contingency plans | 3.32 |
| 2 | Proactive | Anticipate | Situation awareness | Improved information technology or information sharing | Supply chain community to enable information exchange | 3.71 |
| 3 | Proactive | Anticipate | Situation awareness | Improved information technology or information sharing | Early warning communciation system between supply chain partners | 3.9 |
| 4 | Proactive | Anticipate | Situation awareness | Increase in risk avoidance and containment | Supplier risk monitoring systems | 4.86 |
| 5 | Proactive | Anticipate | Situation awareness | Increase in preparedness | Internal early warning system based on weak and strong signal monitoring | 4.18 |
| | Proactive | Anticipate | Situation awareness | Improved information technology or information sharing | Demand forecasting software | 4.75 |
| 6 | Proactive | Anticipate | Situation awareness | Increase in preparedness | Regular updates of delivery times | 5 |
| 7 | Proactive | Anticipate | Robustness | Increase in modularity | Modular product design (shape and material) | 3.06 |
| 8 | Proactive | Anticipate | Robustness | Reduction of inbound lead times | Automation of inbound goods inspection and storage | 3.94 |
| 9 | Proactive | Anticipate | Robustness | Decrease of financial risk | Insurance for potentially disruptive events | 3.03 |
| 10 | Proactive | Anticipate | Robustness | Increase in risk pooling/sharing | Introduction of risk-sharing contractual agreements | 4.3 |
| 11 | Proactive | Anticipate | Robustness | Increase in risk avoidance and containment | Continuous improvement plans for suppliers | 4.72 |
| 12 | Proactive | Anticipate | Robustness | Increase in use of strategic sourcing | Usage of TCO | 4.93 |
| 13 | Proactive | Anticipate | Robustness | Increase in risk avoidance and containment | Robust supplier selection/evaluation criteria | 5 |
| | Proactive | Anticipate | Robustness | Increase in supplier resiliency | Formalized supplier risk management process | 5 |
| 14 | Proactive | Anticipate | Robustness | Increase in supplier resiliency | Standardized supplier vulnerability evaluation (audit) | 5 |
| 15 | Proactive | Anticipate | Knowledge management (pre-disruption) | Increase of labor productivity | Standardized labor routines | 3.02 |
| 16 | Proactive | Anticipate | Knowledge management (pre-disruption) | Increase in preparedness | Strategic gaming | 3.65 |
| 17 | Proactive | Anticipate | Knowledge management (pre-disruption) | Increase in use of distributed decision making | Location-specific empowerment | 4.26 |
| 18 | Proactive | Anticipate | Knowledge management (pre-disruption) | Decrease in response time | Simple reporting systems and structures | 4.79 |
| 19 | Proactive | Anticipate | Knowledge management (pre-disruption) | Improvement of supplier loyalty | Supplier training and development programs | 4.87 |
| | Proactive | Anticipate | Knowledge management (pre-disruption) | Improvement of supplier loyalty | Regular activities to communicate and build relationships/trust with suppliers | 5 |
| 20 | Proactive | Anticipate | Knowledge management (pre-disruption) | Improvement of supplier loyalty | Supplier relationship management system | 5 |

| ID | Strategy | Capability | Element | Objective | Practice | PSM Score |
|---|---|---|---|---|---|---|
| | Proactive | Anticipate | Knowledge management (pre-disruption) | Increase in decision documentation | Application and documentation of standard decision-making criteria in procurement | 5 |
| | Proactive | Anticipate | Security | Decrease in regulatory risk | Introduction/enhancement of product life cycle management | 3.39 |
| 21 | Proactive | Anticipate | Security | Increase in use of distributed decision making | Decision-making with several persons and organizational levels | 3.93 |
| 22 | Proactive | Anticipate | Security | Enhancement of cost minimization techniques | Cross-docking (inventory consolidation) | 4.11 |
| 23 | Proactive | Anticipate | Security | Decrease of financial risk | Usage of futures contracts to hedge commodity prices | 5 |
| 24 | Proactive | Anticipate | Security | Improvement of supplier certification | Clear definition and application of methods, criteria, formats, and approaches for certifying suppliers | 5 |
| | Proactive | Anticipate | Visibility | Increase in preparedness | Standardized and formalized continuity planning | 3.8 |
| | Proactive | Anticipate | Visibility | Increase in preparedness | Supply chain vulnerability mapping | 4.53 |
| 25 | Proactive | Anticipate | Visibility | Increase in preparedness | Capabilities management software (ERP) | 3.55 |
| | Proactive | Anticipate | Visibility | Improved information technology or information sharing | Synchronization of schedules | 3.55 |
| 26 | Proactive | Anticipate | Visibility | Improvement of supplier loyalty | Contracts that align incentives (e.g., revenue sharing or markdown money) | 4.65 |
| | Proactive | Anticipate | Visibility | Increase in preparedness | Regular and formal information exchanges (e.g., once a quarter) with supply chain partners | 4.66 |
| | Concurrent | Adapt | Flexibility | Increase in supplier flexibility | Delayed commitment/production postponement | 3.98 |
| 27 | Concurrent | Adapt | Flexibility | Increase in supplier flexibility | Quantity flexibility (QF) contracts | 4.22 |
| | Concurrent | Adapt | Flexibility | Increase in supplier flexibility | Easy supplier switching contracts | |
| 28 | Concurrent | Adapt | Flexibility | Increase in manufacturing flexibility | Ability to switch from buy to make during regular production | 4.23 |
| | Concurrent | Adapt | Flexibility | Increase in transportation flexibility | Agile delivery route system | 4.37 |
| 29 | Concurrent | Adapt | Flexibility | Increase of manufacturing flexibility | Usage of substitute materials / parts | 5 |
| 30 | Concurrent | Adapt | Flexibility | Increase in transportation flexibility | Usage of flexible transportation volumes | 5 |
| | Concurrent | Adapt | Flexibility | Increase in transportation flexibility | Transportation service alternatives | 5 |
| 31 | Concurrent | Adapt | Flexibility | Increase in transportation flexibility | Transportation mode alternatives | 5 |
| 32 | Concurrent | Adapt | Flexibility | Increase in control through vertical integration | Own logistics capabilities | 5 |
| | Concurrent | Adapt | Redundancy | Increase in idle resources | Increase in idle resources | 3.88 |
| 33 | Concurrent | Adapt | Redundancy | Increase in short term production capabilities | Temporary outsourcing in times of peak demand | 4.78 |
| 34 | Concurrent | Adapt | Redundancy | Increase in idle resources | Inventory and safety stocks to buffer disruptions | 4.9 |
| 35 | Concurrent | Adapt | Redundancy | Increase in redundancy of suppliers | Backup suppliers | 5 |
| 36 | Concurrent | Adapt | Redundancy | Increase in redundancy of suppliers | Dual or multiple sourcing | 5 |

| ID | Strategy | Capability | Element | Objective | Practice | PSM Score |
|---|---|---|---|---|---|---|
| 37 | Concurrent | Respond | Collaboration | Increase in supply chain collaboration | Business continuity plans in collaboration with supply chain partners | 3.21 |
| | Concurrent | Respond | Collaboration | Increase in supply chain collaboration | Allocation of employees in supplier's plant | 3.96 |
| 38 | Concurrent | Respond | Collaboration | Increase in supply chain collaboration | Resource sharing with supplier | 4.68 |
| | Concurrent | Respond | Collaboration | Increase in resource mobilization | Material exchanges between customers of supplier | 4.76 |
| | Concurrent | Respond | Collaboration | Increase in resource mobilization | Exchange network for franchises in cases of no substitutable supplier | 5 |
| 39 | Concurrent | Respond | Agility | Increase in quick decision making | Task force team to deal with disruptive event | 4 |
| | Concurrent | Respond | Agility | Increase in resource mobilization | Securing of additional financial, human and material resources | 4.11 |
| | Reactive | Recover | Contingency planning | Increase in recovery speed | Execution of contingency plan | 4.85 |
| 40 | Reactive | Recover | Market position | Decrease of financial risk | Margin optimization through increase in product prices or decrease in production cost | 3.09 |
| 41 | Reactive | Recover | Market position | Decrease of financial risk | Prioritization of high margin products | 4.34 |
| 42 | Reactive | Learn | Knowledge management (post-disruption) | Increase in supply issue sharing with other parties | Critical information sharing with suppliers | 4.5 |
| | Reactive | Learn | Knowledge management (post-disruption) | Increase in effectiveness of crisis management | Use of experienced employees for crisis management | 4.85 |
| 43 | Reactive | Learn | Knowledge management (post-disruption) | Increase in risk avoidance and containment | Post-disruption analysis inc. re-evaluation of suppliers / competition analysis | 4 |
| | Reactive | Learn | Building social capital | Increase in logistics quality | Usage of trusted (and potentially more expensive) logistics partners | 5 |
| | Reactive | Learn | Building social capital | Increase in supplier quality | Supplier coaching and workshops to recover | 5 |

### A.8.3 SSRES practice adoption ease and effectiveness

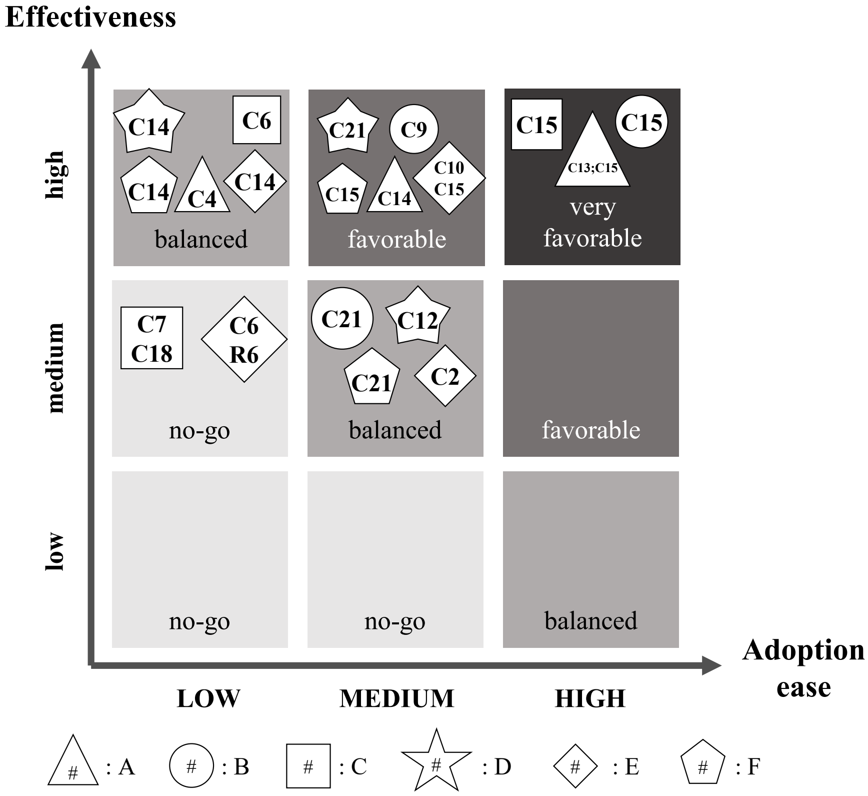


**Figure A-7.** SSRES practice adoption ease-effectiveness matrices partitioned in proactive type

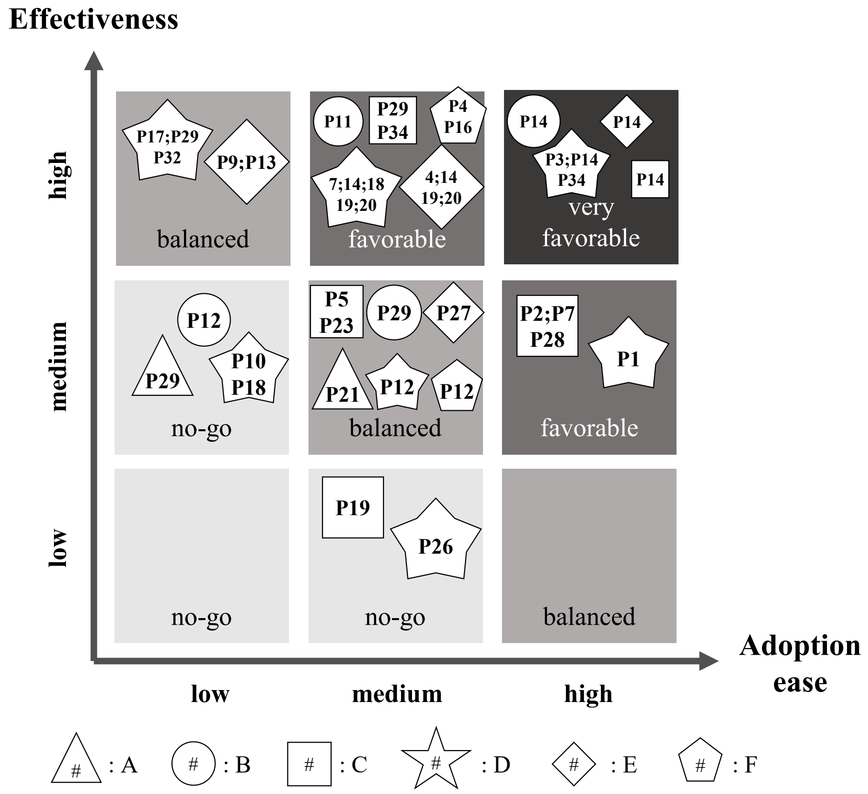


**Figure A-8.** SSRES practice adoption ease-effectiveness matrices partitioned in concurrent type

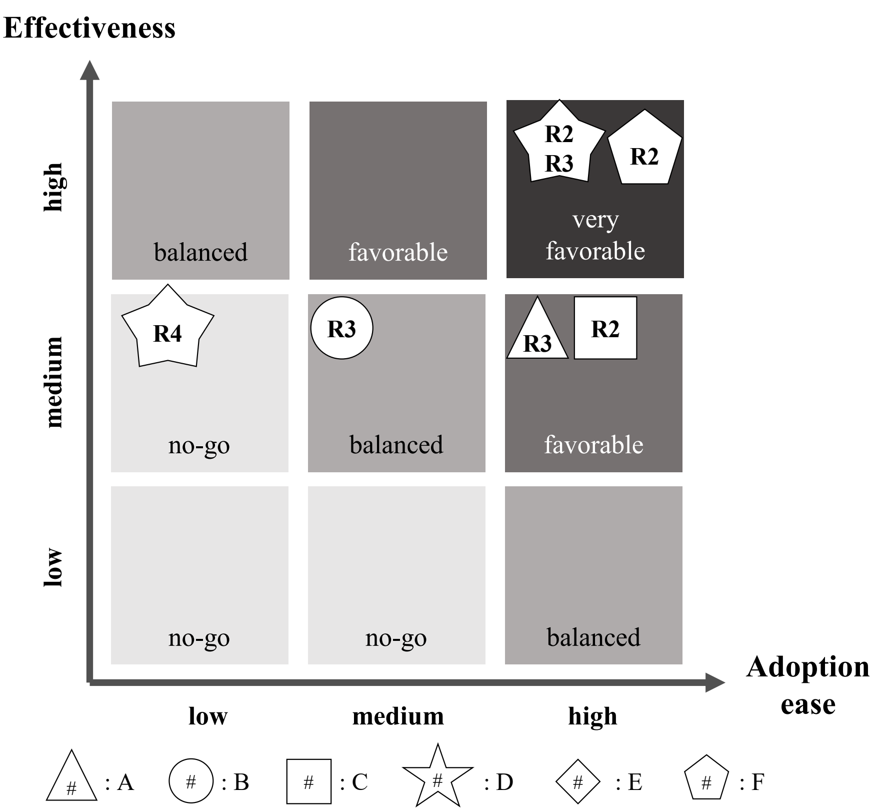


**Figure A-9.** SSRES practice adoption ease-effectiveness matrices partitioned in reactive type

# B Study B: Measuring the effectiveness of supply-side resilience practices

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*This research examines the use of KPIs to measure the effectiveness of supply-side resilience practices. In a two-step systematic literature review analyzing 89 peer-reviewed papers over 22 years, it identifies the KPIs most often used in resilience literature and matches them to known supply-side resilience practices. The theoretical results are applied to a case study with a leading manufacturing company for the practice of robust supplier selection/evaluation criteria. Given the KPIs for this practice, a random forest-based supervised learning method is proposed to predict the effectiveness of this practice based on a set of independent variables. The model is trained on both internal ERP data and publicly available secondary data to help assess suppliers in a pre-screening step, before deciding which supplier to select for a specific product. It represents an integrative, intermediate way to select and evaluate suppliers using real-world data. Compared to the practitioners' individual choice, the model prioritizes a more reliable partner, which would have been able to deliver during the company's supply shortage, proving a 95% effectiveness. The results of this study are to be integrated into a method for measuring and tracking the cost-effectiveness of supply-side resilience practices.*

Keywords: supply-side resilience, manufacturing company, practice-based view, effectiveness, KPIs

## B.1 Introduction

Today’s global supply chains are subject to increasingly turbulent environments (Nitsche & Durach, 2018). Their inherently complex and interdependent nature makes them highly vulnerable to unexpected disruptions. For example, unexpected events with high economic impact, such as Hurricane Katrina in 2005 (Vigdor, 2008), the Japanese tsunami in 2011 (Pettit et al., 2013), and most recently the COVID-19 crisis in 2020 and 2021 (Ivanov, 2020) caused widespread production halts and revenue losses. In order to mitigate the extent of disruption extent caused by such disturbances, numerous companies have implemented approaches for observing and managing supply and production risks, such as comprehensive risk assessments and insurance plans (Fiksel, 2015). However, these approaches have limitations. For example, the statistical assumptions in risk assessments quickly reach their limits when considering low-probability events (Pettit et al., 2010). Moreover, risk management faces challenges of how to deal with ontological uncertainties (“unknown unknowns”) and increasing interdependencies in a globalized world (Dalziell & McManus, 2004). Finally, risk management is often “based on the notion of stability as the ‘normal’ state of affairs” (Fiksel et al., 2014).

Resilience aims to complement risk management by focusing not only on mitigating risks, but also on building capabilities through investments (Melnyk et al., 2014). Furthermore, it aids in addressing those disruptive events, whose probability models are prone to error, and emphasizes the recovery after an unpredictable disruption has occurred (Sheffi & Rice, 2005). Against this backdrop, supply-side resilience (SSRES), i.e., the resilience of the focal company’s upstream supply chain, has become a central topic for procurement and supply management. Therefore, decision-makers are increasingly looking for ways to measure resilience and subsequently integrate it into their supplier decisions (Ivanov & Dolgui, 2021). Many metrics based on both financial and non-financial KPIs have been developed and applied in resilience literature to measure the effectiveness of specific practices (Barroso et al., 2015; Kinra et al., 2020; Munoz & Dunbar, 2015). While each metric covers a certain aspect of resilience, a match of which metrics correspond to which managerial practice is scarcely researched. Furthermore, practitioners are often overwhelmed with the number of KPIs and often do not know which ones to use for which aspect of resilience (Karl et al., 2018). A comprehensive overview of KPIs as proxy indicators of SSRES practices could provide more clarity in the literature and could aid in the derivation of resilience measures of effectiveness. Therefore, the following research question can be posed:

> *RQ1:* What KPIs should be used for measuring the effectiveness of SSRES practices exist?

After KPIs have been identified, the question remains as to with which method best measures the effectiveness of a SSRES. This question refers to the formulation of measures of effectiveness (MOE). Oftentimes these studies are completed with the help of simulations instead of real-world data. This fragmentation leads to the formulation of the second research question:

> *RQ2:* Given suitable KPIs, how can the effectiveness of SSRES practices be measured by MFs with real-world data?

As a theoretical lens, we propose the Practice-Based View (PBV) proposed by Bromiley & Rau (2014), which provides guidance on how fairly common, imitable resources contribute to performance through the shrewd combination of managerial practices. We view SSRES as a fundamentally practice-driven concept connected by intermediary constructs and moderated by contingency variables (Enthoven, 2022).

This research is structured as follows: After a theoretical background on supply-side resilience, KPIs, and effectiveness measurement in Section B.2, the methodology outlining the systematic literature review and the applied case study is presented in Section B.3. Next, the results from the systematic literature review and the cases study are presented in Section B.4. Theoretical and managerial implications are discussed in Section B.5 before the limitations are outlined in Section B.6.

## B.2 Theoretical background

### B.2.1 Resilience

The term resilience can be found in many different disciplines (e.g., psychology and biology), however the focus of this study lies in resilience of companies within their supply chains. One of the most accepted definitions is by Fiksel (2007), who defines resilience as “the capacity of an enterprise to survive, adapt and grow in the face of turbulent change” (Fiksel, 2007, p. 16). Complementary to traditional risk management (Pettit et al., 2010), resilience allows companies to cope with uncertain environments filled with HI/LP events (Sheffi & Rice, 2005). Resilience may be perceived from three perspectives: proactive, concurrent, and reactive (Ali et al., 2017). Proactive resilience follows a business continuity narrative (Pettit et al., 2013) and aims to keep company performance as high as possible at all times, agnostic to specific disruption events (Wang et al., 2018). Concurrent resilience aims to mitigate damage while the disruption is already impacting the company. In contrast, reactive resilience focuses on disaster management by suggesting case-by-case strategies for quickly and effectively recovering after disruptions (Dinh et al., 2012). Supply-side resilience (SSRES) entails the resilience capabilities necessary to mitigate the damage from unexpected, disruptive risks that originate upstream and escalate downstream (Dabhilkar et al., 2016; Pereira et al., 2020). As the interface of the company with the upstream supply chain, the procurement organization is mainly responsible for deploying and allocating the resources to build SSRES capabilities. Notwithstanding the research advancements, resilience is still an abstract term that is difficult to grasp to many researchers and practitioners alike (Pires Ribeiro & Barbosa-Povoa, 2018).

### B.2.2 Supply-side resilience practices

The concept of SSRES entails several higher-order constructs (e.g., phases, strategies, capabilities, elements, objectives) and lower-order constructs (e.g., practices and activities) (Ali et al., 2017; Enthoven, 2022). Dabhilkar et al. (2016) has developed a typology for defining SSRES practice bundles and allocating them to dynamic capabilities. Furthermore, Pereira et al., (2020) has identified managerial practices that bolster proactive and reactive SSRES. To complement the fragmented literature and misalignment of the term "practice", Enthoven (2022) has identified a catalog of 65 SSRES practices and assigned a score to evaluate the relevance of the practice for PSM. Example practices include "education and training of employees to execute supply chain contingency plans" (proactive), "usage of flexible transportation volumes" (concurrent), and "critical information sharing with suppliers" (reactive). Additionally, a practice configuration system was developed to define the context of practice adoption in terms of adoption governance (buyer, supplier, dyad) and adoption level (supplier, product). Notwithstanding the breadth of this research, practitioners still face the challenge of determining which practices are effective for their company and which are not, as well as and how this effectiveness can be measured.

### B.2.3 The role of KPIs in PSM

Procurement and supply management requires a high amount of coordination through processes and activities of resource allocation to create value for the internal and external customers downstream the supply chain and meet their demands (Knight et al., 2022). Against this backdrop, KPIs are often used by organizations to monitor, manage, and control such processes and activities. KPIs "represent a set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization" (Domínguez et al., 2019; Parmenter, 2015). Therefore, they are able to portray the current situation of a company from different vantage points. Each company develops their own KPIs that project their performance values, and these KPIs aid it in tracking its objectives (Parmenter, 2015). In the SSRES context, each company in a supply chain has their own ideas as to what resilience means and how to measure it. However, the correct selection of KPIs is key to being able to measure whether objectives have been reached with an adopted practice.

### B.2.4 Measuring the effectiveness of practices

Effectiveness is defined as the degree to which a practice or an activity is successful or achieving the results that one wants (Price, 1972). Some scholars use performance and effectiveness interchangeably (Donaldson, 2001). The key difference however lies in the link between organizational goals and performance: while performance can be measured through financial KPIs independent of the organization's goals, effectiveness measures how well certain goals have been achieved through performance indicators (Tate et al., 2022). Often used in a military context, the measurement of effectiveness (MOE) expresses the degree to which a KPI achieves an objective (Reed & Fenwick, n.d.) and should allow for the ranking of comparable systems (Pinker et al., 1995). What an MOE does not include is an assessment on the means that were utilized to adopt the practice in the first place, as opposed to efficiency. The following characteristics must be valid for MOE: they must be related to performance indicators, must be dependent on time, and must be tied to environmental conditions. Current efforts to find overall MOE for practices of any kind are characterized by the following challenges: (1) the quantification of subjective attributes (Singh et al., 2016), and (2) the combination of multiple performance measures explaining different attributes into a single measure (Pinker et al., 1995). In the context of this research, the MOE of SSRES practices provides insight on how *successful* the adoption of a practice is at the time of its usage in enforcing SSRES as a set of capabilities. This corresponds to the extent to which practices helped reduce damage during and increase recovery speed after the disruption (Melnyk et al., 2014).

Many methods exist to evaluate the effectiveness of practices with an MOE. For example, many authors use with/without analysis (Hof & Rideout, 1989). On one hand, during-disruption effectiveness for proactive and concurrent practices describes the extent to which the deviation of a KPI is reduced and how much damage could be avoided at full disruption impact (Melnyk et al., 2014). On the other hand, post-disruption effectiveness describes the effect of a practice in reducing the recovery time after full disruption impact. Furthermore, some authors use analytical models and simulations to compare alternative scenarios. For example, some studies simulate supplier alternatives with different characteristics and evaluate the extent of supply disruptions. One study simulates the difference in effectiveness between make or buy during a disruption (Wu & Blackhurst, 2009). Other authors judge the impact of building buffer inventory of critical spare parts versus ad-hoc purchases during a disruption (Cavalcante et al., 2019; Ivanov, 2020; Simchi-Levi et al., 2018). While analytical models and simulations involve many assumptions and simplifications, they can be easily modified to analyze diverse scenarios (Restrepo et al., 2015). Finally, Dabhilkar et al. (2016) measure the effectiveness of SSRES practices in the buying organization through confirmatory factor analysis (CFA) and regression analysis. More specifically, they estimate the strength of relationship between the resilience capability bundles (independent variable) consisting of practices and the speed after recovery (dependent variable). Using a mixed methods approach, they translate qualitative data (i.e., interview transcripts) into quantitative data (Likert scale).

## B.3 Methodology

The methodology of this research is essentially subdivided into two stages. While the first stage includes a systematic literature review to answer RQ1, the second stage is an application of the knowledge acquired in the first stage to a real-world example to answer RQ2.

### B.3.1 Literature review

Considering the increasing relevance of deductive methods in operations and supply chain management due to its growing body of literature, a systematic literature review ensures that no relevant research has been overlooked (Karl et al., 2018; Pereira et al., 2014). In their work, Thomé et al. (2016) critique the current paucity of SLR guidelines in OSCM and propose a more rigorous method, which follows clear guidelines to ensure more transparency, reliability, and reproducibility of findings (Karl et al., 2018). The guideline can be adapted to the needs and research of the individual authors (Thomé et al., 2016). For the purpose of this research, the following steps can be identified: (1) the formulation of goals, (2) the location of studies, (3) the selection of studies, and the (4) analysis and synthesis to evaluate whether the goals have been reached.

For the first step, researchers aim to answer the first research question and partition the approach into three sub-goals:

*Sub-goal 1*: The compilation of the most used and relevant SSRES practices

*Sub-goal 2*: The compilation of KPIs used in the context of SSRES

*Sub-goal 3*: The assignment of KPIs to SSRES practices

Regarding the first goal, Enthoven (2022) has compiled a list of 65 SSRES practices assigned to different objectives, capabilities, and strategies according to the model of Ali et al. (2017). During the course of this study, this list will be used and filtered according to relevance. Furthermore, the second sub-goal is achieved by drawing from insights from Karl et al. (2018), who has connected non-financial KPIs to established resilience elements. Building on this, we aspire to descend to a further operational level that matches the identified KPIs with specific SSRES practices to address the third sub-goal. Overall, the first two sub-goals are necessary to reach the third sub-goals.

In the second step, the location of studies across the three goals was addressed. For this purpose, two academic databases (Scopus and Web of Science) were searched according to the interface of three constructs: supply chain resilience, procurement, and KPIs. The overview of the keywords per construct as well as the final logical search string is provided in Table B-1.

**Table B-1.** Constructs, keywords, and the resulting logical search string for the SLR (adapted from Karl et al., 2018)

| Constructs | Keywords | Logical search strings |
|---|---|---|
| Supply chain resilience | Supply chain resilience<br>Resilient supply chain<br>Resilience / resilient<br>Supply chain vulnerability<br>Vulnerability<br>Risk in supply chain | (supply chain* AND resilien* OR risk OR vulnerab*) AND (purchasing OR procurement OR supply manag*) AND (resilien* OR risk OR vulnerab) AND ((performance AND (indicat* OR measure* OR metric*)) OR KPI) |
| Procurement | Purchasing<br>Procurement<br>Supply management | |
| KPIs | Performance indicators<br>Performance metrics<br>Performance measures<br>KPI | |

Going further, a search period of 21 years was defined (January 2000 to December 2021), corresponding to the time period since the first publications on resilience emerged (Pereira et al., 2014; Karl et al., 2018). Altogether, 11,765 documents were found when making the first database request. In a first filtering step, irrelevant articles and duplicates were removed based on the title and keywords, reaching a compilation of 5,552 unique documents. A second filtering step involving the screening of introductions and conclusions. Screening led to a shortlist of 231 articles. A deeper dive into this pre-selection and filtering according to rigorous criteria (i.e., peer review, existence of empiricism, organizational vantage point) led to a final selection of 89 articles to address sub-goal 2.

For the final step, the analysis and synthesis of the data could be accomplished in several ways (Thomé et al., 2016). For this research, the final selection of papers was fully read and inspected for the relevant SSRES practices and the KPIs to measure its performance or effectiveness. While the practice was matched with the catalog from Enthoven (2022), the KPI was further investigated in terms of perspective (who measures) and target (who is measured). This ultimately resulted in an assignment of KPIs to practices, which acts as a foundation for the second stage of this research.

### B.3.2 Case study

To address RQ2, this research applies the findings of the first stage to measure the effectiveness of a specific SSRES practice adopted in industry. The data for this case is provided from a key partner within a research consortium from the Swiss manufacturing industry. With a revenue of 150 million Swiss Francs, the company is one of the global leaders for electrical infrastructure products. Their purchasing volume of 93 million Swiss Francs is designated for product groups including raw materials (i.e., copper and aluminum) as well as electrical components. In general, the company has not been strongly affected by the COVID-19 crisis yet has experienced partial supplier defaults. While 66 percent of their suppliers are located in Switzerland, 32 percent are located in Europe (excl. CH) and 1 percent in the rest of the world.

The case study follows a five-step process:

*Step 1*: Select a SSRES practice

*Step 2*: Derive the independent variables from the available data

*Step 3*: Construct the target KPI, i.e., the dependent variable

*Step 4*: Train, test, and validate the model

*Step 5*: Measure the effectiveness of the model versus human effectiveness

The first phase of the research consisted of selecting a suitable SSRES practice to evaluate. This choice was made based on the highest perceived need of the company. The second phase involved the prioritization and construction of the target KPIs and a choice of whether to conduct an individual KPI analysis and merge the results, or to conduct a composite KPI analysis for more direct access. It also includes building the connection from the KPI to the MOE. The third phase entailed the data collection and exploratory analysis of company-internal supplier data and complementary secondary data, from which an aggregated feature set of independent variables was extracted.

To achieve generalization and application of our model beyond our case company in the future, three kinds of data were used: (1) data already stored in internal ERP systems (e.g., revenue of the supplier, backup suppliers), (2) data that can automatically be fetched from external data sources, and (3) subjective evaluations on the supplier, obtained during negotiation and first contact. Regarding the first type of data, the supplier data and order history data from the company was made available and included a list of all orders made by the procurement organization from November 2018 to November 2021. It contained 27,144 historical entries from 436 unique suppliers. Regarding the second type of data, currency volatility and country risk data, such as the one-year volatility (della Corte et al., 2016) and the World Risk Index (Welle & Birkmann, 2015) were candidates for extraction. Regarding the third type of data, the responsible buyer rated the reachability (Azevedo et al., 2013; Pereira et al., 2014; Pettit et al., 2010), friendliness (Pettit et al., 2010; Soni et al., 2014), price in relation to market price (Ali et al., 2017; Pettit et al., 2010), the political stability (Pettit et al., 2010), and flexibility (Ali et al., 2017; Pereira et al., 2014; Pettit et al., 2010) of the supplier on a four-point Likert scale.

This allows a model to profit from human expertise and obtain company specific information otherwise not quantifiable by hard data. Following the data collection phase, the fourth and fifth phases include the development, training and application of a multi-variable supervised machine learning model, aiming to predict the target KPI for other scenarios than the one selected. The final phase is dedicated to comparing the model against the human benchmark to finally make a statement about the MOE between the scenarios.

## B.4 Results

### B.4.1 Supply-side resilience practices and KPIs

The 89 articles revealed 6 different KPIs assigned to a total of 18 different SSRES practices. All KPIs are from the perspective of the buyer. Distinctions can be made in the target (buyer versus supplier). The manifestation of KPIs can be determined supplier-specifically, product-specifically, or aggregated over the entire procurement volume and revenue (Carvalho et al., 2011; Sheffi, 2005).

First, cashflow-related indicators such as *procurement ROI*, *stock level* and *capacity utilization* are commonly used. The *procurement ROI* is a financial metric used in PSM to put in relation the investments into goods and services and the return in terms of revenue. This was found in relationship with robust supplier selection/evaluation criteria (P3), disruption task force team (C3), usage of substitute parts in production (C4), margin optimization (R2). In practice, the *capacity utilization* is often measured as the ratio of actual to maximum potential output, consistent with a given capital stock (Nelson, 1989). Studies measuring the effect of make-or-buy decisions (C1), flexible transportation volumes (C5), and transportation switching alternatives (C6) have been identified (Gunasekaran et al., 2001, 2004). Many firms measure the *stock level* and maintain safety stock, as missing stock disrupts the production flow and stops downstream value creation. Studies measuring the effect of upstream risk monitoring systems (P1), in-sourcing production (C1), during-disruption information sharing with suppliers (C2), safety stock of critical items (C7), and backup suppliers (C8) have been identified.

Furthermore, KPIs from the perspective of the buyer linked to specific supplier performance have been used. These include the *order lead time* (Carvalho et al., 2012; Wu & Blackhurst, 2009) and *on-time delivery of goods* (Carvalho et al., 2011; Cavalcante et al., 2019; Hallgren & Olhager, 2009; Ivanov, 2020; Wagner, 2008). The *order lead time* was found in studies focused on a supplier relationship management (P5), insourcing production (C1), and transportation-related practices (C5, C6). Furthermore, two reactive practices, i.e., resource sharing with supplier (R1) and documentation and dissemination of disruption implications (R4) were found in relationship to the order lead time. The on-time delivery of goods was found in combination with five practices (P3, P5, C4, R1, R4). Finally, the *supplier rejection rate* (Chan, 2003; Gunasekaran et al., 2004; Huang & Keskar, 2007) has been mentioned, which is highly related to the quality of delivered goods, as it counts the ratio of rejected goods due to defaults and quality issues to the total amount of delivered goods (Gunasekaran et al., 2004). From all KPIs, the most relationships of this KPI (supplier rejection rate) with practices has been found (P2, P3, P6, C1, C4, R1, R3, R4). This is mainly due to the high importance of goods quality in procurement. Generally, the most diverse set of KPIs was found for C1, R1, and R4. A full overview of the findings is provided in Table B-2.

**Table B-2.** SSRES practices and matched KPIs

| **Perspective** | | | | | **Buyer** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Target** | | | | | **Buyer** | | | **Supplier** | | |
| **ID** | **Adoption level** | **Practice** | **Capability** | **PSM Score** | **Procurement ROI** | **Capacity utilization** | **Stock level** | **Order lead time** | **On-time delivery of goods** | **Supplier rejection rate** |
| P1 | Buyer | Upstream risk monitoring systems | Anticipate | 4.86 | | | ✓ | | | |
| P2 | Supplier | Continuous improvement plans | Anticipate | 4.3 | | | | | | ✓ |
| P3 | Buyer | Robust supplier selection/evaluation criteria | Anticipate | 4.72 | ✓ | | | | ✓ | ✓ |

| Perspective | | | | | Buyer | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Target** | | | | | **Buyer** | | | **Supplier** | | |
| **ID** | **Adoption level** | **Practice** | **Capability** | **PSM Score** | **Procurement ROI** | **Capacity utilization** | **Stock level** | **Order lead time** | **On-time delivery of goods** | **Supplier rejection rate** |
| P4 | Buyer | Supplier training and development program | Anticipate | 5 | | | | | | ✓ |
| P5 | Buyer | Supplier relationship management system | Anticipate | 5 | | | | ✓ | ✓ | |
| P6 | Dyad | Incentive-aligning contracts | Anticipate | 4.65 | | | | | | ✓ |
| C1 | Buyer | Insourcing production | Respond | 4.23 | | ✓ | ✓ | ✓ | | ✓ |
| C2 | Dyad | Information sharing with suppliers | Respond | 4.5 | | | ✓ | | | |
| C3 | Buyer | Disruption task force team | Respond | 4 | ✓ | | | | | |
| C4 | Buyer | Usage of substitute parts in production | Respond | 5 | ✓ | | | | ✓ | ✓ |
| C5 | Buyer | Flexible transportation volumes | Adapt | 5 | | ✓ | | ✓ | | |
| C6 | Buyer | Transportation switching alternatives | Adapt | 5 | | ✓ | | ✓ | ✓ | |
| C7 | Buyer | Safety stock of critical items | Adapt | 4.9 | | | ✓ | | | |
| C8 | Buyer | Backup suppliers | Adapt | 5 | | | ✓ | ✓ | | |
| R1 | Dyad | Resource sharing with supplier | Recover | 4.68 | | | | ✓ | ✓ | ✓ |
| R2 | Buyer | Margin optimization | Recover | 4.34 | ✓ | | | | | |
| R3 | Dyad | Information sharing with suppliers | Learn | 4.5 | | | ✓ | | | ✓ |
| R4 | Buyer | Documentation and dissemination of disruption implications | Learn | 4 | | | | ✓ | ✓ | ✓ |

Authors have proposed single indicators (Carvalho et al., 2011, 2012; Wu et al., 2007; Zavala et al., 2018), multiple indicators (Cardoso et al., 2015; Ivanov, 2020; Li et al., 2020), and indices to aggregate various correlated metrics (Barroso et al., 2015; Hosseini et al., 2019; Munoz & Dunbar, 2015; Pettit et al., 2013; Rajesh, 2020), oftentimes mixing financial and non-financial KPIs. Composite indices based on linear models are suited for SSRES, as long as performance indicators are without synergy and conflict effects (Barroso et al., 2015). For example, Ivanov (2020) models the impact of epidemic outbreaks and compared production-inventory dynamics, estimated lead time service level, financial performance, and lead-time performance.

In a final step, the KPI must be mapped on a time axis in order to apply the with/without principle. These mappings should link the KPIs to the objectives before, during, and after a disruption. As during-disruption effectiveness for proactive and concurrent practices describes the extent to which damage could be avoided at full disruption impact (Melnyk et al., 2014), the difference of the KPI $\Delta_{PC}$ between the scenario "with practice" and scenario "without practice" at full disruption impact is taken as the MOE (see Figure B-1). While procurement ROI and on-time delivery of goods measure this difference from a lower, fixed "without" scenario towards the upper "with practice" scenario curve of an ideal-typical disruption, the capacity utilization and order lead time deviation measure the difference from an upper, fixed curve to the lower curve. In the case of the stock level, the difference describes the buffer that the "with practice" scenario would still have at full disruption impact. Note that the reference stock level is flat only for illustration purposes. This means that a continuation of the pre-disruption, reference level of a KPI for the "with practice" scenario for P/C practices would correspond to a 100% effectiveness. In contrast, if the "with" curve would follow the path of the "without curve", this would correspond to a 0% effectiveness.

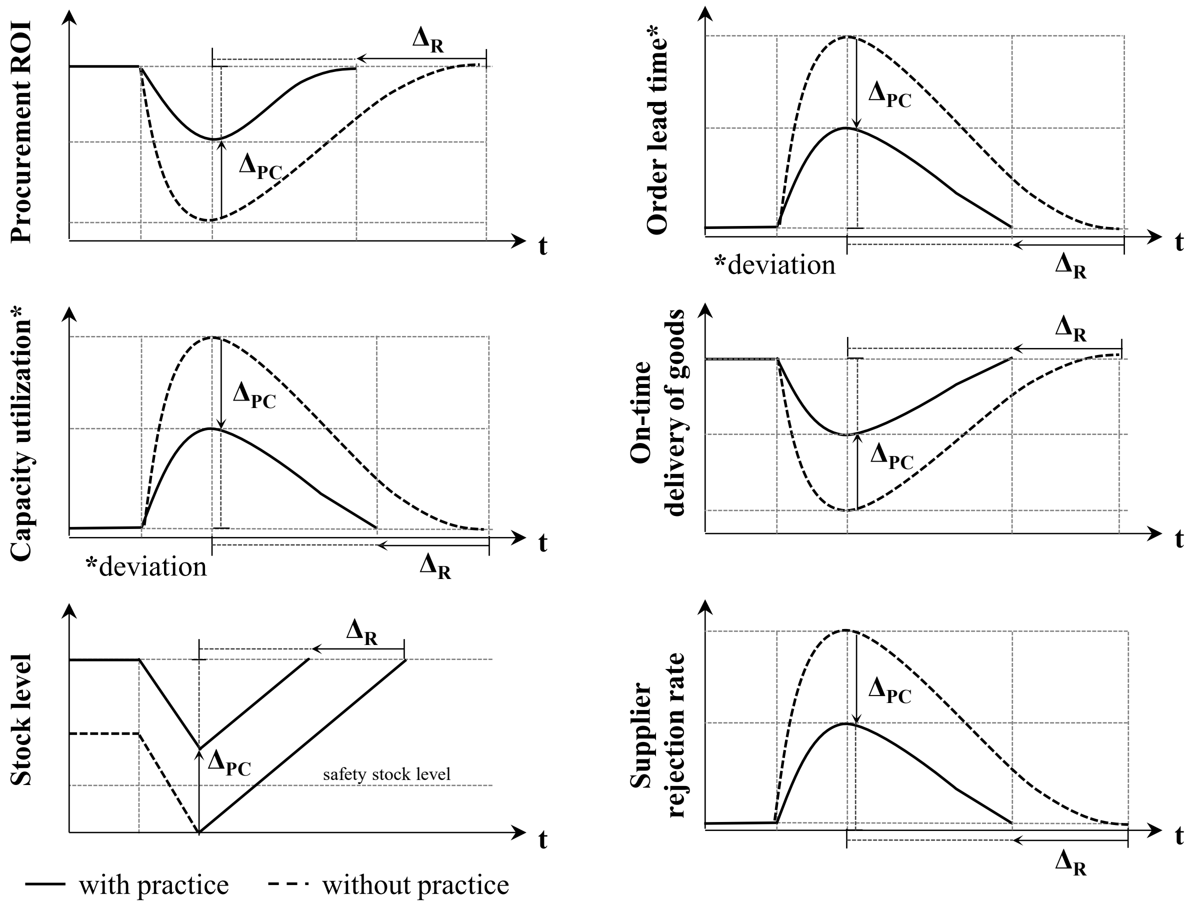


**Figure B-1**. MOE for proactive/concurrent practices (PC) and reactive (R) practices

Considering that post-disruption effectiveness describes the effect of a practice in reducing the recovery time after full disruption impact, the MOE for all reactive practices $\Delta_R$ associated with the KPIs is measured by the difference in recovery time. This means that an instant recovery at the point of full impact for the "with practice" curve would correspond to an effectiveness of 100%. Experiencing full recovery at the same time as the "without practice" scenario corresponds to 0% effectiveness. The MOEs $\Delta_{PC}$ and $\Delta_R$ are always measured in percentage.

### B.4.2 Case study: Robust supplier selection/evaluation criteria (P3)

In the following section, the findings and conceptualization of the previous section will now be applied in a case study.

#### Step 1: Selecting the SSRES practice

The company has chosen the SSRES practice "robust supplier selection/evaluation criteria" (P3) due to highest perceived need. During the period this research was conducted, the company had supplier selection/evaluation criteria based on subjective metrics only. The CPO and risk manager realized that there would be potential for improvement. A pipeline was developed to ultimately measure the effectiveness of this practice. The pipeline for Steps 2, 3, and 4 has been developed for the subsequent steps to analyze P3 (see Figure B-2).

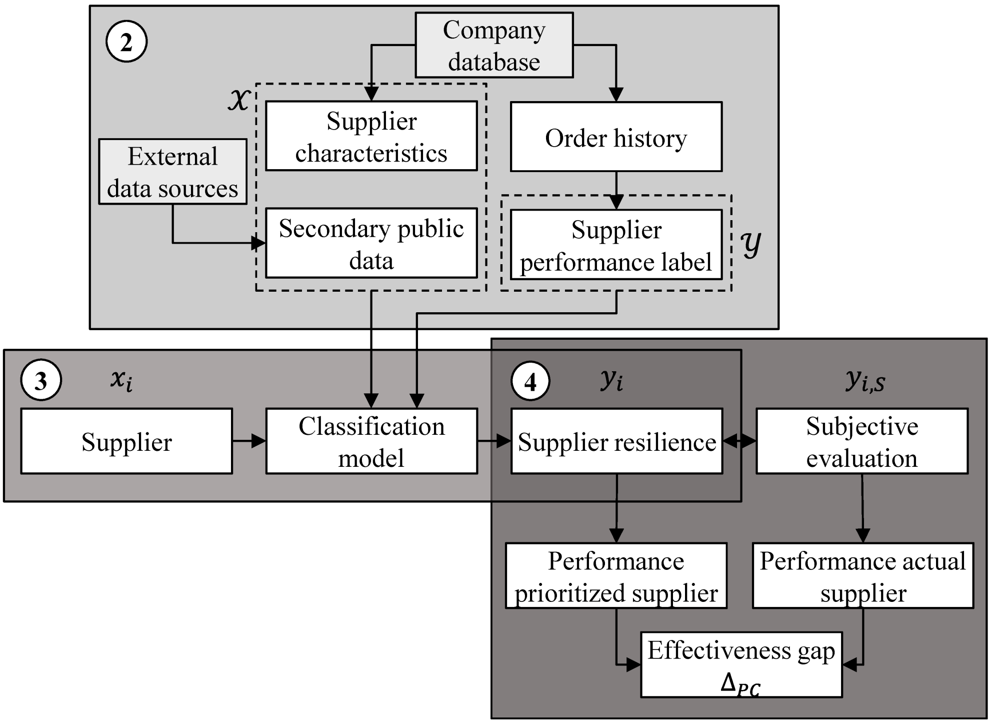


**Figure B-2.** Pipeline for the effectiveness measurement of P3

### Step 2: Derive the independent variables from available data

The dataset $\mathcal{X}$ of size $n \times m$ was compiled, based on supplier characteristics and secondary supplier data, where $n$ is the number of suppliers and $m$ is the number of independent variables (features). After merging both the supplier data set inferred from the order history and the external data sources, a final data set could be prepared. Researchers extracted the *procurement volume* through a supplier, if the delivered product is *success-critical*, the *supplier's revenue*, and the l*anguage of correspondence with the supplier* (Ali et al., 2017; Azevedo et al., 2013; Pereira et al., 2014; Pettit et al., 2010). Additionally, the location of the supplier and the used currency allowed researchers to derive the *world risk index* and the *currency volatility* through automated access to external data sources. Lastly, the company evaluated the 98 suppliers with the highest revenue to the above listed subjective features. As the supplier selection/evaluation criterion should be able to prioritize suppliers before the disruption, only data from before March 2020 was considered.

**Step 3: Constructing the target KPI**

The results from Table B-2 indicate the relevance of three KPIs when considering P3: procurement ROI, the on-time delivery of goods, and the quality of delivered goods. Recent studies suggest measuring resilience solely according to the on-time delivery and quality of delivered goods individually (Carvalho et al., 2011; Cavalcante et al., 2019). As managers require performance metrics to monitor supply chain operations (Nudurupati et al., 2011) and to understand the resilience of increasing complex supply networks (Zavala et al., 2018), the researchers suggest a single metric consisting with the relevant KPIs instead of a metric set to rank suppliers for a subsequent selection. Furthermore, according to Nudurupati et al. (2011, p. 281), we posit non-financial indicators "[…] act as the leading indicators for the financial performance." For this reason, this study prioritizes the on-time delivery of goods ($\alpha_i$) and the quality of delivered goods ($\beta_i$). This is confirmed by the company, as, in their words, "a KPI overload would lead quickly to not using it anymore". Let the dependent target variable be

$$y_i = f(\alpha_i, \beta_i) \in \{0,1,2\}$$

where $y_i = 0$ stands for "low priority", $y_i = 1$ stands for "medium priority", and $y_i = 2$ stands for "high priority". The results are compared to a human benchmark in the final phase and therefore a discrete ternary classification set is chosen. The effectiveness would ultimately be measured by comparing how the model would have chosen the supplier configuration according to the target variable versus how the purchasers would have chosen it. The prioritization must be compared per product, so that suppliers for different products do not compete. In case the model's supplier prioritization performed better, the practitioner was asked for validation.

The researchers propose a metric integrating the on-time delivery penalized by delay severity and the quality of goods in terms of the percentage of faulty objects in the delivery. Thus, from the order history from before March 2020[49], we extracted the service level in terms of planned and actual delivery dates per order, as well as the quality level per order, such that for each supplier $i \in \{1, \dots, n\}$ the following sequence can be defined:

[49] The dataset was split in half at March 1st, 2020 to reflect all pre-disruption data and during/post-disruption data.

$$\mathcal{S}_i = \left\{\sigma_1^{(i)}, \dots, \sigma_{p(i)}^{(i)}\right\} \in \mathbb{Z}$$

where $\sigma_j^{(i)}$ is the deviation in days from the agreed delivery date of the $j$th delivery from supplier $i$ and $p(i)$ is the total number of deliveries from a supplier $i$. $\sigma_j^{(i)} > 0$ implies a late delivery, whereas $\sigma_j^{(i)} < 0$ implies an early delivery. We define as the subset of $\mathcal{S}_i$ the subset of all non-zero elements:

$$S_i^{\pm} = \left\{\sigma_j^{(i)} \in \mathcal{S}_i \mid \forall j \in \{1, \dots, p(i)\}, \sigma_j^{(i)} \neq 0\right\}$$

The on-time delivery ratio of a supplier $i$ can then be calculated as:

$$\widetilde{\alpha_\iota} = 1 - \frac{\|S_i^{\pm}\|}{\|\mathcal{S}_i\|}$$

Being an element in $[0,1]$, the formula includes the quotient between the cardinality of all non-zero elements and the cardinality of the total set. Therefore, a high number of non-zero elements is penalized, resulting in low $\widetilde{\alpha_\iota}$, an indication of many delivery time deviations. In order to take the delay extent into account, $\widetilde{\alpha_\iota}$ is penalized with the help of the deviation from the agreed delivery date in days (Kamalahmadi & Mellat-Parast, 2015). Therefore, comparing two suppliers with the same service level, but with different average deviations, the one with the higher deviation is penalized more heavily. We define the delay penalty $p_i$ of a supplier $i$ as follows:

$$p_i = \frac{\sum_{z \in S_i^{\pm}} |z| - \min\limits_i \sum_{z \in S_i^{\pm}} |z|}{\max\limits_i \sum_{z \in S_i^{\pm}} |z| - \min\limits_i \sum_{z \in S_i^{\pm}} |z|}$$

This formula sums the absolute number of deviation days and normalizes this to a scale $[0,1]$. Note that both positive (late) and negative (early) deviations are penalized. While late deliveries may result in production halts and customer dissatisfaction, early deliveries may pose challenges in terms of storage, shelf life, and early payment requests.

Finally, the quality of the delivered goods can be derived by calculating the average inverse of faulty products per delivery $f_j^{(i)}$:

$$\beta_i = \frac{\sum_j 1 - f_j^{(i)}}{\|\mathcal{S}_i\|}$$

We then aggregate the on-time delivery with the delay penalty and quality ratio to arrive at the continuous target variable:

$$\widetilde{y_i} = (\widetilde{\alpha_i} * p_i) * \beta_i = \alpha_i * \beta_i$$

The company provided us with a supplier evaluation list, in which the responsible purchasers have rated the most important existing suppliers with values in the set $\mathcal{Y}_S = \{0,1,2\}$. The evaluation is done yearly and is based on subjective evaluation and heuristics. Afterwards, the team acts on poorly rated supplier to improve their score in the future. This evaluation is neither based on hard performance metrics, nor on scientific methods, but rather on the "gut feeling" of decision-makers.

To make the target variable $y_i$ directly comparable to the human baseline benchmark, which includes a ternary subjective evaluation of each supplier, the continuous variable $\widetilde{y_i}$ is discretized to $y_i$ introducing the thresholds $t_0$ and $t_1$.

$$y_i = \begin{cases} 0 \text{ if } \widetilde{y_i} < t_0 \\ 1 \text{ if } t_0 \leq \widetilde{y_i} \text{ and } \widetilde{y_i} < t_1 \\ 2 \text{ if } \widetilde{y_i} > t_1 \end{cases}$$

Internal thresholds that allow variable discretization are often used (e.g., in credit scoring systems) to enable easy interpretation of results and justify specific decisions (Navas-Palencia, 2020). The thresholds $t_0$ and $t_1$ were chosen to match the distribution of the subjective evaluation and confirmed subsequently in an interview with the company. This hints to the fact that anyone with a penalized service level of around 95 percent is highly reliable, whereas the range from 85 percent to 95 percent is fairly reliable, and anything under that is considered unreliable. Due to lacking order history or erroneous order entries, $y_i$ was only available for $n_y = 75$ samples. The remaining 23 labels were then generated through Multivariate Imputation through Chained Equations (MICE), the most common and generalizable imputation method to make up for missing data (van Buuren & Groothuis-Oudshoorn, 2011).

**Step 4: Training the supplier ranking model**

After developing the dataset $\mathcal{X}$ and set of target variables $\mathcal{Y}$, we could define the sequence

$$\mathcal{M} = \{(x_1, y_1), \dots, (x_n, y_n)\}$$

of pairs from $\mathcal{X} \times \mathcal{Y}$. Our aim was to find a function $f: \mathcal{X} \rightarrow \mathcal{Y}$, which predicts $y_i \in \mathcal{Y}$ for arbitrary $x_i \in \mathcal{X}$. The discrete target variable $y_i$ allowed us to formulate this as a classification problem.

The real-world data noise, the low samples-to-features ratio (Hua et al., 2005), and the presence of few categorical features led us to tree-based classification algorithms that can also be applied to small data sets. We applied the random forest (RF) algorithm, a supervised machine learning method that consists of a combination of decision trees to provide accurate and stable predictions, as it frequently outperforms other classification methods such as logistic regression and $k$ nearest neighbors (Couronné et al., 2018). In order to further increase the robustness of our results, RF was applied within a bootstrapping framework (Cox et al., 1994). One major advantage of tree-based models is their high resistance against irrelevant variables in comparison to neural networks or kernel methods (Ahmed & Abdel-Aty, 2013). During model performance analysis, we evaluated the inclusion of features by considering the variable importance, which measured how effective a feature is at reducing uncertainty in the model (Loecher, 2020).

With a dataset $\mathcal{X}$ of size $n_x = 98$, the distribution of labels revealed highly imbalanced data, i.e., many samples leaning toward $y_i = 0$ or $y_i$=2. This may bias prediction results and influence how well the model predicts the supplier rank. Using Synthetic Minority Oversampling Technique (SMOTE), the label distribution of classes was balanced by generated samples for the minority classes in order to reach $n_x = 132$ (Chawla et al., 2002). Since this set was still rather small, results may suffer from low generalizability. To mitigate this, a method known as bootstrapping was applied; a resampling technique in which samples are drawn randomly with replacements from our data set to build a model. By repeating this step many times, the distribution of the results gets closer to the real distribution (Cox et al., 1994). A summarization of all data manipulation steps is demonstrated in Table B-3. In our case, $n_x = 132$ instances were drawn randomly with replacement from the data set.

**Table B-3.** Steps to augment training set

| **Description** | $\boldsymbol{n_x}$ | $\boldsymbol{n_y}$ |
|---|---|---|
| Cleaned dataset | 98 | 75 |
| MICE for missing labels | 98 | 98 |
| SMOTE for balancing classes | 132 | 132 |

| | | |
|---|---|---|
| Bootstrapping during training | 132 | 132 |

To prevent the model from overfitting (i.e., an inherent lack of generalizability), regularization steps were introduced. We thus implemented a grid search on hyperparameters such as the number of trees, the maximum depth of trees, the maximum number of features, and the maximum number of samples. Moreover, during training of the model, a $k$-fold cross validation was performed, randomly splitting the data in training and testing sets in each iteration, over which model performance metrics were averaged.

A total of 500 bootstrapping iterations was performed, each time drawing 132 samples with replacement from the generated data set and performing a 5-fold cross-validation on the data set. Thereby, in each iteration, the samples were split into five sets. The model is trained on four sets (80 percent) and tested on the remaining data (20 percent). Each bootstrapping iteration consisted of five training and testing phases, so that each of the five sets is used for testing once. The mean scores over all bootstrapping iterations of the cross-validation steps were stored and afterwards evaluated.

**Step 5: Measuring the effectiveness of the ranking model**

First, to measure the predictive performance of our approach, several metrics on the testing data sets were calculated. For investigating overall model performance, the accuracy of our predictions was first calculated (the supplier rankings). We also calculated the precision, recall, and the AUC ("area under the curve"). The overall accuracy of our prediction models is 79 percent. However, high precision values (86 percent), high recall (73 percent), and high AUC (80 percent) are equally as important for evaluating the model.

To get a more detailed understanding of the role of individual variables in predicting supplier resilience, the importance of each variable for the prediction model was investigated. The term "variable importance" reflects the relative contribution of each measure to the overall prediction model. Thus, the higher this value, the higher the variable's importance for making accurate predictions. The results show that the variable measuring the revenue of a supplier is the most important one for predicting supplier ranking. At the same time, reachability ranks similarly high. Friendliness, political stability, currency volatility, and the World Risk Index are of relatively lower importance. The theoretical implications of these results are elaborated in the discussion section.

Finally, the model's ranking results were compared against the subjective evaluations of purchasers for the most critical 5 products (Product A, B, C, D, and E). Overall, there was a difference in supplier preference between the model and the purchaser for 3 products (Product B, C, and E). While 2 products (C and E) did not experience any shortage during the past three years, the company faced challenges in acquiring good-quality Product B on time in mid-2020 with Supplier $B_1$. For this reason, the company switched to their backup Supplier $B_2$ in July 2020, when their safety stock was used, and continued production beginning of August. With the current model, the company would have prioritized $B_2$ over $B_1$ and prevented the production halt of approximately 1 week. Assuming a similar average quality rate over the deliveries $\beta_i$, choosing $B_2$ would reach an MOE of around 95% for that time period, considering a 95% service level, because another supplier capable of delivery would have been chosen. This proves the high effectiveness of the proposed model.

## B.5 Discussion and limitations

In the following, the results of the literature review and the case study will be discussed and critically reflected against existing research.

Previous research has matched KPIs to abstract supply chain resilience elements (Karl et al., 2018). The present study is the first one to the knowledge of the author that attempts to match KPIs with concrete SSRES practices. Using the insights from Enthoven (2022), which connects SSRES practices with SSRES elements via specific objectives, the results from the literature review against the results from Karl et al. (2018) can be validated. For 14 out of 18 practices tied to SSRES elements, at least one KPI could be matched with a KPI mentioned in Karl et al.'s (2018) findings. This confirms the validity of our findings. Furthermore, the MOEs tied to the KPIs applied to both P/C and R practices have been designed in a way that allows both empirical and subjective measurement to make a statement about their effectiveness in reaching the respective objective. While the ideal-typical curves that measure the deviation of the KPIs during and after a disruption are merely for guidance, they portray how different each KPI must be treated in considering disruptions.

Regarding the case study, a composite KPI was constructed to account for all mentioned KPIs of the proactive practice. The multiplication of on-time delivery, severity of delay, and the quality of delivered increase the chance of statistical significance. The inclusion of a quality factor through multiplication is quite common in Total Cost of Ownership and Life Cycle Cost calculations (Bremen et al., 2010). The development of the model for robust supplier selection/evaluation revealed some interesting insights. From the available data and constructed features, the supplier revenue was the most decisive feature in the presented model. As a hard financial metric, this determines the size of a supplier. Often, but not always, a high revenue reflects the health of the company and may be an indicator for its dependency on their buyers (Melnyk et al., 2021). Most subjective factors (i.e., friendliness, flexibility, market price, political stability) have scored low importance, apart from reachability. Thus, it is inferred that reachability – an indicator for trust (Soni et al., 2014) – is the feature that can be best estimated subjectively through regular contact with the supplier. The low importance that flexibility assumed was surprising, considering that this is an established element of resilience (Ali et al., 2017; Skipper & Hanna, 2009). This may stem from human bias in the decision, as for many the score did not reflect how suppliers reacted in case of a plan change, but rather how flexible they "seemed". The less important factors might be more relevant when we consider reactive resilience in the disaster management. Further efforts may be made to extend the model for reactive disaster management cases, especially for those companies that have been more strongly affected. Furthermore, country-specific features including political stability, currency volatility, and the World Risk Index played a minor role in resilience in our model, which may be due to the high percentage of suppliers in Switzerland, a highly politically stable country. Low-cost country sourcing would offer an extended perspective.

Applying machine learning algorithms on real-world data – often incomplete and underrepresented – inherently comes with challenges. We have therefore introduced preprocessing two steps to augment and improve the data set. MICE is a method to impute incomplete data by Fully Conditional Specification (FCS) (van Buuren & Groothuis-Oudshoorn, 2011). Unlike other methods such as Joint Modeling (Schafer & Yucel, 2012), FCS is the best suited method for our approach, as it does not require assumptions about the distribution of missing data but compares missing data on a variable-by-variable basis (van Buuren & Groothuis-Oudshoorn, 2011). Suppliers with rank 1 have potential for supplier development and should be tracked so that they do not slip into rank 0. As the given label distribution was inherently imbalanced, we used SMOTE to oversample this minority class (Chawla et al., 2002). Due to the lack of sample data, the undersampling of the majority classes – often used in literature (Japkowicz, 2000; Provost & Fawcett, 2001) – would not have been an alternative. Through the generation of synthetic minority data, our model can be further generalized "to carve broader decision regions" (van Buuren & Groothuis-Oudshoorn, 2011).

## B.6 Conclusion, limitations, and outlook

This study's contribution is two-fold: As an answer to the first research question ($RQ_1$), it provides an overview of the most frequently used KPIs in connection with SSRES practices. A systematic literature has identified 8 KPIs distributed among 18 practices, where order lead time and quality of delivered goods had the highest occurrence for practices (7 and 6, respectively). The majority of KPIs were non-financial, as they mainly drive the financial KPIs. The results are theoretically underpinned by the PBV. Additionally, a guide on how to measure the effectiveness with these KPIs per type of practice is provided. While the MOEs for proactive and concurrent practices are mainly based on damage mitigation at full disruption impact, the MOEs for reactive practices are inferred from the difference in recovery speed after a disruption.

Second, the findings from the first contribution are applied to a leading Swiss manufacturing company, resulting in a practical and fast supplier rank prediction model as a robust supplier selection/evaluation criterion. Through data mining of primary ERP data (supplier list and order history), as well as publicly available secondary data and no further insights into the supply chain, a data set estimating a composite KPI was created. The data set was augmented through MICE, SMOTE, and bootstrapping, achieving a model accuracy score of 79 percent of predicting correctly, whether a supplier is resilient, partially resilient, or not resilient. This is coupled with high precision (86 percent), recall (73 percent) and high AUC (80 percent). With the help of the model's prediction, purchasers can automatically pre-assess new suppliers in the future using previously unused ERP data. The model's supplier ranking was tested against the buyer ranking and it was found that the model outperformed the subjective evaluation and could have led to the prevention of a production halt in mid-2020.

Naturally, the results of this study come with limitations and constraints. The literature review is based only on the body of literature from two academic databases from the past 21 years. Furthermore, no snowball search was applied, so there might be potential for identifying related literature that could complement the current results. Regarding the case study, many companies from the manufacturing industry currently struggle with proper digital documentation, especially in procurement, one of the major barriers to digitalization (i.e., "garbage in garbage out"). Whereas some studies (Carvalho et al., 2011; Cavalcante et al., 2019; Ivanov, 2020) use purely simulated data, we managed to clean and augment real-world data, increasing the practicability of the approach. When comparing the model and feature set to existing supervised machine learning approaches to predict resilience (Carvalho et al., 2011), our model is one of the first that is based on real-world supplier data. As with all real-world data, that in the order history and the supplier evaluation may be incomplete or erroneously entered manually. Through exploratory data analysis, these pitfalls have been identified and considered, such as filtering statistically insignificant variables and cleaning erroneous entries. Additionally, the small sample size drove us to apply resampling techniques and other statistical approaches. Using techniques like MICE, SMOTE, and bootstrapping during training allowed us to fill gaps and increase the sample size. However, these techniques may come with a few caveats, such as artificial bias. Finally, the proposed method is just one of many methods which can be used to derive an MOE. For a full picture, other methods individually investigating the identified KPIs based on other methods and more detailed simulations should be conducted to achieve comparability and evaluate the model robustness.

In future research endeavors, the feature set could be augmented by the additional integration of more company- and supply-chain specific variables stemming from external data sources, such as proprietary risk data, sustainability factors, and creditworthiness of suppliers. Moreover, the implementation of APIs to ERP systems would allow a real-time and seamless transfer of data to further automate the estimations.

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# C Study C: Determining the cost of resilience: an activity-based costing approach for buyers

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*The purpose of this study is to propose an approach to cost resilience practices addressing low-probability, high-impact disturbances originating in upstream supply chains. A multiple case study with three manufacturing companies was conducted to identify and characterize the activities embedded in supply-side resilience practices. An activity-based costing approach aided in estimating the individual cost of practices throughout a disruption cycle of the SARS-CoV-2 outbreak. The findings shed light on how much manufacturing companies spend on their resilience practices and what type of resources they utilize. The author identifies a catalog of 81 activities distributed over 21 practices. The author finds that many reactive, post-disruption practices require proactive setup and maintenance resources. Furthermore, most practices are highly personnel-intensive, and the investment in practices is directly proportional to company size. The findings can help supply managers review resource allocation and allocate cost drivers to resilience practices for their buying organization.*

Keywords: supply-side resilience, practices, cost, activity-based costing, purchasing and supply management, procurement, practice-based view

## C.1 Introduction

Over the past few decades, purchasers of manufacturing companies have focused on reducing procurement costs and making their upstream supply chains as efficient as possible to gain a competitive advantage (Ueltschy Murfield et al., 2021). One prominent strategy for reducing these costs is outsourcing production to low-cost countries, which is accompanied by inherent risks (Bremen et al., 2010). To counter these risks, procurement professionals in manufacturing companies (MCs) mostly use supply chain risk management (SCRM) measures to identify, analyze, and contain risks (Ivanov et al., 2017). SCRM has been proven effective in addressing risks with empirical data to develop respective probabilistic models; however, the struggle of many manufacturing companies due to recent unexpected disturbances, such as the Japanese earthquake in 2011 (Pettit et al., 2013) or the SARS-CoV-2 outbreak in 2020 (Ivanov & Das, 2020), has demonstrated that these risk models have limitations (Fiksel et al., 2014; Peck, 2016). As a simultaneously emerging concept, supply chain resilience (SCRES) and its associated constructs have gained increasing attention from practitioners and researchers (Pettit et al., 2019).

As most disturbances emerge upstream of the supply chain and escalate into disruptions downstream, purchasers play a key role in addressing them. Against this backdrop, the upstream version of SCRES was coined “supply-side resilience” (SSRES) (Pereira et al., 2020). SSRES is a set of capabilities enforced by elements and practices that align with different strategies (A. Ali et al., 2017). Adopting and maintaining these practices incurs costs generated by several resource pools. While several quantitative studies have provided complex operations research models to estimate the cost of flexible transportation routes or backup suppliers (Aldrighetti et al., 2021; Zavala et al., 2018), none of these studies provide a holistic and straightforward approach to measure the cost of SSRES practices. This leads to the first research question:

*RQ1*: What cost elements are associated with SSRES practices for MCs?

Each SSRES practice requires setup and maintenance before it is used. After the cost elements have been identified, the aggregation and allocation of the cost elements into the different stages of a practice is sought. This will help identify the relationship between expenditures in certain practices and higher-order SSRES constructs. This leads to the second research question:

*RQ2*: How could the setup, maintenance, and usage of SSRES practices be costed for MCs?

Against this backdrop, the study attempts to develop an adaptable approach to determine the "cost of resilience," i.e., the additional expenditure to implement specific SSRES measures within the upstream supply chain. The research is outlined as follows: Following a theoretical background in Section 2, the methodology of the research is introduced in Section 3. Next, the results of the case studies are presented in Section 4, after which they are critically examined in light of existing literature in a discussion in Section 5. Finally, the research is concluded with limitations and an outlook in Section 6.

## C.2 Theoretical background

### C.2.1 Supply-side resilience

The concept of resilience on an organizational or supply chain network level has been well-established in literature (Fiksel, 2015; Peck, 2016; Ponomarov & Holcomb, 2009; Wieland & Wallenburg, 2013). In general, resilience is defined as the capability of organizations or supply chains to respond quickly to unexpected events to restore operations to either the previous or a better level of performance (Christopher & Peck, 2004; Pereira et al., 2014; Pettit et al., 2013). The concept entails several theoretical constructs in literature, such as strategies, phases, capabilities, elements, objectives, and practices (A. Ali et al., 2017). While traditional risk management involves a set of techniques that aid in the identification, assessment, and evaluation of concrete risks through probabilistic models, it faces challenges addressing the high-impact low-probability (HI/LP) risks not supported by enough empirical evidence that could cause catastrophic consequences (Pettit et al., 2010). In other words, resilience complements risk management not through targeted risk avoidance measures, but through event-agnostic measures enabling capabilities to adapt, recover, and learn when HI/LP risks cause disruptions.

Most supply chain disturbances (i.e., the occurrence of risks) originate upstream and escalate into disruptions downstream. Thus, a company's purchasing and supply management (PSM) function acts as the interface between these risks and the remaining vital functions of the company. According to Pereira (2014, p. 628), PSM has evolved from a "simple business function accountable for planning, implementing, evaluating, and controlling purchase decisions" to a vital resource management function (Ellram & Carr, 1994; Lysons & Farrington, 2010; Monczka et al., 1998). PSM can "organize, deploy and control the necessary assets, resources, routines, and processes to facilitate organizational resilience, which can become a competitive advantage" (Pereira et al., 2020, p. 2). Against this backdrop, the concept of SSRES focuses on building the capabilities of buying companies to address upstream disturbances with potentially catastrophic consequences. Few studies have been conducted to identify and analyze the theoretical constructs of SSRES. One such study, by Pereira et al. (2020), identified several practices and categorized them into proactive and reactive phases, such as backup suppliers and flexible transportation modes. The authors viewed SSRES as a dynamic state with an evolutionary component and thus used a dynamic capabilities view as the theoretical underpinning. Similarly, Enthoven (2022) compiled a list of 65 SSRES practices tied to different objectives (e.g., increase in transport flexibility, increase in supply chain redundancy), elements (e.g., situation awareness, flexibility, redundancy), capabilities (e.g., ability to respond, ability to recover), and strategies (proactive, concurrent, reactive). The author structured the constructs through the theoretical lens of the practice-based view (PBV), concluding that the shrewd combination of imitable and learnable practices achieves a sustainable competitive advantage before, during, and after a disruption (Bromiley & Rau, 2014; Enthoven, 2022). For this research, the same theoretical approach will be taken.

### C.2.2 Measuring the cost of resilience

A key challenge in the literature and in practice is the operationalization of SSRES in monetary terms. The supply-side resilience-specific cost literature reveals two cost types: (1) costs resulting from disruption damage and (2) costs resulting from investments in resilience.

The first sub-stream contains quantitative methods to evaluate the monetary damage caused by disruptions and introduce reactive mitigation measures to contain the damage (Klibi et al., 2010; Snoeck et al., 2019). Different cost drivers in this sub-stream include backlog cost, damages cost, delay penalties, procurement cost penalties, recovery costs, transport costs, and transshipment costs (Aldrighetti et al., 2021). For instance, Pires and Barbosa-Povoa (2018) define an objective function to both incorporate financial and non-financial indicators, i.e., the expected net present value compared with and without disruption. Numerous studies have measured this damage using non-delivery penalties per fixed period of time, taking the form of elevated transportation costs and missed revenue (Jabbarzadeh et al., 2018; Riccardo et al., 2021; Snoeck et al., 2019). However, many of these studies are concerned with the probability of disruption to estimate expected costs (Aldrighetti et al., 2021; Klibi & Martel, 2012), standing in direct conflict with established resilience definitions, which assume that the HI/LP risks causing disruptions have insufficient underlying empiricism to be predicted (Pettit et al., 2010).

Studies focusing on the second type of cost, i.e., proactive investments in resilience constructs, can be sub-divided into network and company-level perspectives. From a network perspective, studies are mostly concerned with supply chain network design (Aldrighetti et al., 2021; Bottani & Montanari, 2010). For example, Cardoso et al. (2015) offer a multi-objective programming approach coupled with a quasi-total cost approach that considers initial investment into processes, process expansion investments, and storage capacity extension investments for multiple nodes in a supply chain. Furthermore, another study within this domain investigates facility location problems for measuring the additional cost of redundant capacities across the supply chain (Fan et al., 2018). From a company-level perspective, Govindan et al. (2020) measure the additional cost (i.e., product cost, logistics cost, and quantity discount) for “resilient” suppliers. Another study focused on supplier configuration and respective resilience surplus costs (Fahimnia et al., 2018). Schütz and Tomasgard (2011) introduces the construct of flexibility in terms of volume, delivery, and operational decision making for supply chain planning under uncertain demand in the Norwegian meat industry with the help of a stochastic programming model, keeping in mind production cost, transportation cost, and inventory cost (Schütz & Tomasgard, 2011). A study from the airline industry described resilience costs as the difference between delay costs with and without proactive measures in place (Cook et al., 2016).

Most of the resilience cost literature reviewed focuses on the additional expenses of individual practices and measures; their results are rarely applicable to multiple practices. Taking the breadth of SSRES practices into consideration, the literature lacks a holistic approach to measuring the cost of proactive, concurrent, and reactive SSRES practices.

### C.2.3 Costing methods in PSM

PSM offers many costing methods for practice cost calculation yet no study in resilience cost literature could be identified that makes use of this knowledge. These costing methods are most often used in the context of decision-making, especially in MCs. These decisions include supplier selections, supplier evaluations, make-or-buy decisions, or general investment decisions for the adoptions of practices (Degraeve & Roodhooft, 1999; Dogan & Aydin, 2011; Ellram & Siferd, 1993; Fill & Visser, 2000; Kumar & Nagpal, 2011; Sharma, 2016). A set of the most prominent methods including strengths, weaknesses, and suitability for this research will be introduced below (see Table C-1).

**Table C-1.** Established costing methods in PSM

| Method | Cost drivers | Strengths | Weaknesses | Suitability |
|---|---|---|---|---|
| **Traditional costing** (Schönsleben, 2007) | Cost structure of a product | • Simplicity | • Only usable in product costing applications<br>• Low integration power with PBV<br>• Mainly limited to physical assets | Weak |
| **Activity-based costing** (Cooper & Kaplan, 1987) | Fixed costs in individual activities allocated to different resource pools | • High accuracy<br>• Transparency of cost calculations<br>• Broader focus for measuring practice costs<br>• High integration power with PBV | • High complexity<br>• High effort to acquire relevant data | **Strong** |
| **Life cycle costing** (APICS, 2008) | Phases of a product life cycle: development, production, service, usage, and disposal | • Transparent evaluation of costs | • High complexity<br>• Difficult to predict future costs<br>• Mainly limited to physical assets | Weak |
| **Supply chain costing** (Slagmulder, 2002; Wagner, 2008) | Cost determination along the entire supply chain (from raw material to end customer) | • Detailed cost breakdown per supply chain node<br>• High accuracy | • Low transparency<br>• High complexity, especially for small companies<br>• Requires data collection and sharing from suppliers | Moderate |
| **Total cost of ownership** (Ellram & Siferd, 1993) | Unit-related additional costs of a procurement good or activity, which may include the former as elements | • High flexibility<br>• High accuracy<br>• High controllability | • High complexity<br>• Moderate integration power with PBV | Moderate |

*Traditional costing* is conducted under the premise that information about procurement goods can be found in the cost structure of a product (Schönsleben, 2007). A simple calculation methodology, it is solely usable in product costing applications and does not exhibit the required flexibility for usage on SSRES practices. *Activity-based costing (ABC)* is an approach developed by Cooper and Kaplan (1988) for “the costing and monitoring of activities, which involves tracing resource consumption and costing final outputs. Resources are assigned to activities and activities to cost objects. The latter use cost drivers to attach activity costs to outputs” (CIMA, 2013). While traditional absorption costing focuses on volume-related cost drivers (e.g., labor hours), ABC focuses on transactional cost drivers (e.g., number of purchase orders) that incur costs, facilitating the allocation of overheads toward specific products, projects, or practices (Cooper, 1987). As an SSRES practice can be considered a set of activities according to the PBV (Bromiley & Rau, 2014), ABC is a strong fit and could aid in tracking costs incurred and re-allocating these to individual practices.

*Life cycle costing (LCC)* “seeks to optimize the cost of acquiring, owning, and operating physical assets over their useful lives by attempting to identify and quantify all the significant costs involved in that life, using the present value technique” (Woodward, 1997, p. 336). While it entails a transparent evaluation of costs, it can reach its limits, as it requires future cost predictions and can become quite complex (Korpi & Ala-Risku, 2008). In the context of SSRES practices, LCC is restricted to asset-based practices such as inventory-related practices or the monetary aspect of supplier selection. *Supply chain costing* considers activities and costs upstream and downstream the supply chain, as well as their interdependencies (Wagner, 2008). While on one hand this methodology allows full supply chain transparency, it reaches its limits in terms of practical feasibility, especially for smaller companies, as it requires additional supply chain actors to provide information about incurred cost (Lalonde & Pohlen, 1996; Slagmulder, 2002). Therefore, its suitability for costing SSRES practices is moderate. Finally, *Total Cost of Ownership (TCO)* is a type of calculation designed to help a buying company evaluate direct and indirect costs and benefits of a product or service to be purchased over its entire life cycle (Degraeve et al., 2005; Ellram, 1993; Ellram & Siferd, 1998; Wagner, 2008; Wouters et al., 2005). While TCO has been adopted increasingly in MCs for supplier comparison purposes, its uses have extended to project and practice cost calculations (Hurkens et al., 2006; Smytka & Clemens, 1993). However, due to its high complexity and difficulty of integration with the PBV, it has only a moderate fit for costing SSRES practices. Summing up, ABC is viewed as the most suitable costing methods for approaching SSRES practices. To the knowledge of the author, currently no research exists combining these two topics.

## C.3 Methodology

### C.3.1 Research design and case selection

For this study, a multiple case study design was selected to study the costs of SSRES practices, as this design allows for a broad data foundation to make both individual and comparative analyses (Yin, 2009). In comparison to single case studies, multiple case studies allow for a wider potential to discover relationships and theoretical constructs from the results (Gustafsson, 2017). As implications are grounded in different empirical evidence, they provide more convincing conclusions (Eisenhardt & Graebner, 2007; Gustafsson, 2017; Hilmola et al., 2005). The unit of analysis are SSRES practices adopted by MCs, with some being conducted by PSM, and in others by risk management professionals overseeing supply-side risks. For the purpose of finding generalizable results, a theoretical sampling technique was used, selecting manufacturing companies based on specific sampling criteria. These criteria require that (1) SSRES has become one of the top strategic priorities, (2) there should be a structured buying organization within the company, (3) a minimum of 10 SSRES practices have been adopted, (4) a product or product part has suffered a disruption in the past 3 years. For increased access and convenience, case companies from Switzerland matching the criteria were chosen. Previous contact with these companies had been established in the context of a project consortium. The full overview of case companies is provided in Table C-2.

**Table C-2.** Interview partners

| Company | Industry | PV in 2021 (in million CHF) | Position of interviewee | Experience of interviewee in years |
|---|---|---|---|---|
| A | Engineering | 2,230 | CPO<br>Risk manager | 23<br>6 |
| B | Automotive | 1,400 | CPO<br>Controller<br>Assistant buyer | 14<br>7<br>11 |
| C | Electronics | 93 | CPO<br>Head of controlling | 23<br>6 |
| D | Automotive | 230 | Head of global sourcing<br>Buying assistant | 18<br>3 |
| E | Engineering | 9 | Head buyer | 5 |

Characteristic of all case companies was the direct procurement volume making up a large part of revenue. For anonymity reasons, the procurement volume cannot be revealed. Studying five cases allowed for a variety of environments and requirements to SSRES practice adoption, increasing external validity through within-case analysis and subsequent cross-case analysis (Eisenhardt, 1989; Yin, 2009).

The access point for estimating practice costs with ABC is *practices*. As Bromiley and Rau (2016) define it, a practice is a set of activities that can be categorized into different types: setup activities, maintenance activities, and usage activities.

- *Setup activities*: For all three phases during a cycle, setup activities for a practice are executed once. This includes all pre-adoption activities, such as gathering knowledge, applying knowledge to the company and context, planning and calculations, and finally, the implementation process itself.
- *Maintenance activities*: This type of activity is intended to ensure that the practice may be used at any given time during a disruption cycle. They can be distinguished as failure-based maintenance (FBM), usage-based maintenance (UBM), and condition-based maintenance (CBM; Bertrand et al., 1991). FBM describes a maintenance activity after a fault or error has occurred. An example of this is a production machine that breaks and must be repaired. UBM is a type of preventive maintenance that is conducted after a set period of time or usage (e.g., once per year or every X machine hours). CBM is another type of preventive maintenance, conducted when certain performance criteria are not met, such as a production machine reaching a critical temperature (Bertrand et al., 1991).
- *Usage activities*: Usage activities are those that make use of a set-up and maintained practice. The practice is “used” with the intent to achieve an effect that builds resilience. Typically, pre-disruption usage activities are regularly executed (e.g., risk monitoring of software). During a disruption, activities may typically be executed multiple times during the disruption and/or applied in multiple contexts (e.g., dual sourcing for two different products influenced by the disruption).

This subdivision serves in identifying and categorizing practices in the data collection step.

### C.3.2 Data collection

Primary data was collected by interviewing the case partners listed in Table C-2. Two rounds of interviews were conducted. In the first round, 120-minute semi-structured interviews were conducted with each company. The SSRES practices from Enthoven (2022) were filtered according to adoption by the companies since January 2019. For each of the adopted practices, 3-5 activities were identified, according to company-specific context. The scope, period, and frequency of execution per activity were collected to contextualize the cost estimations. Initial analyses of practice and activity distribution across the SSRES capabilities and strategies could be made and was presented to interviewees in a second round. The interviews were recorded and transcribed from German and translated into English. Other sources such as public documents and protocols from past conversations with the case companies in the context of the consortium project were used to complement and validate information provided in the first round.

In the second round of interviews, the representative with the necessary access to data or specific knowledge was interviewed in a 90-minute interview regarding the costs of activities. These individuals were asked to prepare the necessary data for applying the ABC to this breakdown, resulting in several data points for each practice. First, the estimations of the frequency of activity execution and the incurred costs per activity execution were collected. The product of these two variables allowed for an estimation of the total investment. Second, with the total cost per activity across the disruption cycle, an allocation of costs to resource pools, including staff/personnel, material/equipment, cash, infrastructure/facilities, and information, was made by the practitioners. From this, independent resource cost drivers assigned to the individual resource pools were derived, and their individual impact on all resilience measures was estimated.

The observed timeframe to execute any activity is a *disruption cycle*, which includes the phases before, during, and after a disruption. The phase before the disruption begins usually starts as soon as the recovery of the last disruption has been completed and a stable performance state has been achieved. The outbreak of SARS-CoV-2 began in March 2020 and lasted well into 2021 in terms of cases and lockdowns (Rozhkov et al., 2022). The observation period for SSRES practices for this study was thus fixed from January 2019 until March 2022 (27 months) to allow for enough time before and after the beginning of the disruption. While it was a challenge to isolate the disturbance and its associated cascaded disturbances into a single disruption cycle, the interviewees were urged to focus only on the effects of this disturbance.

### C.3.3 Data analysis

The interview transcripts and provided data on adopted practices, associated activities, costs per activity, and resource pool distribution for each activity were analyzed within cases and across cases (Yin, 2009). The analysis was conducted in order to answer research questions RQ1 and RQ2. First, a within case analysis was carried out, providing an overview of mostly descriptive data, highlighting among others the proportions of cost across the categories of practices as well as the expenditure-to-PV ratio. Second, a cross case analysis aids in (1) identifying relationships between costs and company characteristics and (2) determining patterns in resource distribution within SSRES practices. The discussion will then compare the results with existing literature.

## C.4 Results

### C.4.1 Activity identification

Across all five cases, 21 different SSRES practices were identified, each used by at least one case company. Of those, 8 fell within the proactive strategy (P), 8 fell within the concurrent strategy (C), and 5 fell within the reactive strategy (R). Each practice contained between 3 and 5 activities, yielding 81 activities in total (40 setup activities, 22 maintenance activities, and 19 usage activities; see Appendix, Table C-4). The activities were categorized into their respective types and execution phases: pre, during (dur.), and post-disruption (po.), according to the aggregated results of the cases.

P practices include the most activities that lasted over all three periods. Apart from P4 and P9, all usage activities lasted for the entire cycle. Regarding P4, robust supplier selection criteria played a secondary role during and after the disruption. The companies knowingly accepted a higher risk for the replenishment of critical parts and for the sake of damage containment. For P9, contract negotiation, drafting, and renegotiation occurred before the disruption. During the disruption, flexible incentive-aligning contracts were no longer a priority. On average, P practices were the most frequently executed, with up to 2,000 repetitions of bug fixes and regular updates within 27 months for Company A.

As concurrent practices require certain preparation, setup activities were mostly executed before the disruption, apart from C8. While the assembly of a task force team requires pre-disruption preparation, the nature of the disruption may fall into the specialties of only certain stakeholders that are not available before. In this case, a specialist in finding a supplier for a missing spare part in Asia was introduced into the task force as soon as the disruption hit (Company B). C7 was the only one of the C practices whose activities extended into post-disruption, and the only one of the C practices that lasted over all three periods. This is due to its generalizable nature and the importance of communication throughout all periods, according to the CPO. The correlation between concurrent practice activity execution and the during-disruption execution phase was 0.25, confirming the loose execution timing of concurrent practices.

R4 (prioritization of high-margin products) was the only R practice that lasted over three periods. The R practices that fill the during-disruption area all started pre-disruption. With some exceptions, reactive practices were generally set up, maintained, and used after the disruption. As expected, most activities of all types associated with reactive practices were also executed post-disruption. In general, the strategy descriptions mostly referred to the actual usage of the practice and less to the setup and maintenance.

### C.4.2 Within case analysis

In the following, the results of cost aggregation of the activities to the different manifestations of SSRES strategies (proactive, concurrent, reactive) are outlined per case company. The full overview is provided in Table C-3.

**Table C-3.** Cost in thousand CHF and number of adopted practices per company per strategy

| | **Company A** | | **Company B** | | **Company C** | | **Company D** | | **Company E** | |
|---|---|---|---|---|---|---|---|---|---|---|
| SSRES strategy | Cost (tCHF) | No. of pract. | Cost (tCHF) | No. of pract. | Cost (tCHF) | No. of pract. | Cost (tCHF) | No. of pract. | Cost (tCHF) | No. of pract. |
| proactive | 3,318 | 7 | 1,720 | 7 | 174 | 4 | 692 | 6 | 57 | 4 |
| concurrent | 2,346 | 7 | 1,381 | 4 | 381 | 4 | 395 | 5 | 83 | 3 |
| reactive | 342 | 4 | 451 | 3 | 42 | 2 | 124 | 2 | 12 | 2 |
| $\Sigma$ | **6,006** | **18** | **3,552** | **14** | **597** | **10** | **1,211** | **13** | **152** | **9** |
| **$\Sigma$ / (3*PV)** | **0.27%** | | **0.25%** | | **0.64%** | | **0.53%** | | **0.56%** | |

Company A, as the largest case company with a PV of CHF 2.23 billion, adopted 7 proactive, 7 concurrent, and 4 reactive practices for which it spent CHF 3.318 million, CHF 2.346 million, and CHF 342,000, respectively. This means that proactive practices make up around 55% of total expenditure. In total, the cost of the 18 SSRES practices results in around CHF 6 million over 3 years, which constitutes an average annual 0.1% of the PV. The most cost-intensive practices for Company A were P4 (CHF 1.45 million) and C5 (1.35 million). P4 used mostly personnel resources, as Company A has a large supplier base where supplier evaluations need to be maintained and conducted continuously. Regarding C5, Company A built a buffer inventory using mainly material resources.

As a large company in the automotive supply industry with CHF 1.4 billion PV, Company B adopted 7 proactive, 4 concurrent, and 4 reactive practices with costs of CHF 1.72 million, CHF 1.381 million, and CHF 451,000, respectively. Noticeable is the 48% proportion of total expenditure. With a total of CHF 3.55 million cost over 3 years, this amounts to an annual expenditure ratio of 0.08% with respect to the PV. The highest cost driver for Company B were P5 (CHF 620,000) with high personnel resource intensity and C5 (CHF 571,000), with high material resource intensity. Regarding P5, supplier training and development "has become extremely important for us over the last few years. Our systems are very detailed. We do not accept any suppliers who only participate in this halfheartedly." (CPO, Company B). Their strong market position allows Company B to make these demands toward suppliers.

Furthermore, Company C spent CHF 597,000 for 10 practices with a 118% additional expenditure into concurrent over proactive practices. As a moderately large company in the electronics industry with a PV of CHF 93 million, it spent 0.64% on SSRES practices. The highest expenditure was made in the concurrent practices, especially C4 and C5. Regarding C4, Company C paid high insurance premiums in case an LSP could not deliver due to mobility restrictions. In the words of an interviewee, "booking a premium insurance has become standard procedure now when we source from China. Looking back, we should have done it like this the whole time." (Head of global sourcing, Company C). This implies that—for Company C—savings efforts on transportation represented a high vulnerability. The additional expenditure was necessary and saved them from damage. Regarding C5, a critical parts safety stock has been meticulously maintained from the beginning of the period.

Company D spent CHF 1.2 million on 12 practices, making up 0.53% of the CHF 230 million PV. Proactive SSRES takes the lead in terms of expenditure with a 57% to concurrent SSRES. Its highest single expenditure of CHF 220,000 was the formation of a disruption task force to devise a contingency plan (C8). When commenting on the effectiveness of the expenditures, an interviewee stated that “these experts cost the company a lot for their experience for 6 months, but they managed it extremely well. Their experience not only instilled confidence in many employees, but they helped us devise a plan to get our buying organization through the worst phase of Corona” (Head of global sourcing, Company D).

As the case company with the smallest PV of CHF 9 million from the set, Company E spent around CHF 152,000 on SSRES practices over the past three years, i.e., around 0.56% annually of their PV. The highest expenditure proportion (55%) was made in concurrent practices, especially in safety stock (C5; CHF 36,000). This safety stock ensured that Company E “managed to bridge the switch from a Chinese supplier to a German one, as we were paying air freight during the period where container ships were stuck in Shanghai. We could not do that forever” (Head buyer, Company E). Furthermore, considerable cost was incurred for insourcing production (C7; CHF 23,000) when the Company stopped receiving a critical part from a supplier in Eastern Europe.

### C.4.3 Cross case analysis

From the collected results, several observations during cross-case analysis could be identified. The first set of observations refers to the relationship between company characteristics and the expenditure into SSRES practices.

> *Observation 1.1 (O1.1):* Companies generally spend very little on SSRES practices compared to their procurement volume.

Across all cases, an annual expenditure-to-PV ratio between 0.08% (Company B) and 0.56% (Company E) was determined. Considering the damage mitigation and recovery acceleration potential of some practices, these are generally small costs, but can have enormous impact on the company’s supply-side performance and consequently on the service level to their customers. All case companies have experienced a supply shortage at one point during the past three years, and all have recovered.

> *Observation 1.2 (O1.2):* Company size is directly proportional to the expenditure into proactive SSRES strategies.

Notwithstanding the high spread of absolute spend between companies in the respective SSRES strategies, larger companies spent a significant amount of their budgets on proactive SSRES (55% for Company A, 48% for Company B, 57% for Company D). Proactive practices are mainly resource-intensive in terms of personnel, considering the high wages in Switzerland in comparison to other countries. On the other hand, the smaller companies in the set (Companies C and E) have the highest expenditure into concurrent practices (57% and 55%, respectively). An interviewee from Company C explains that "there are many barriers to why we do not invest so much into the first type of practices, one of which is that we need cash in case there is an emergency" (Head of controlling, Company C). This implies that the lower expenditure ratio into proactive SSRES does not cause the higher expenditure ratio into concurrent practices, but rather can be explained by the need for cash reserves.

> *Observation 1.3 (O1.3):* Company size is somewhat proportional to expenditure-to-PV ratio.

The available data provides a proportionality pattern between expenditure ratio and company size. While this set reveals the maximum ratio (0.63%) for the second smallest company and the smallest ratio for the second largest company (0.25%). Therefore, a full proportionality could not be extracted.

> *Observation 1.4 (O1.4):* Larger companies have a broader portfolio of SSRES practices.

Finally, there is a positive relationship between the number of practices and the expenditure into SSRES practices. Larger companies usually have more personnel and a broad focus of practices. Regarding contracts with suppliers (P2, P8) and logistics service providers (C3, C4), larger companies have the necessary leverage as well as in-house lawyers and controlling personnel to devise, negotiate, and draft contracts.

The second set of observations relate to the link between practices, resource pools, and phases.

> *Observation 2.1 (O2.1):* All SSRES practices require a high proportion of personnel resources.

Notably, personnel constituted by far the highest percentage cost, with an average of 49% over all activities across all practices and companies. This makes the two main cost drivers the number of time units worked and the salary per time unit. Furthermore, material and equipment made up a major part of some practices, especially within the concurrent strategy (e.g., C5, C6, and R1). Naturally, these activities were mainly related to stock. Cash investments were relatively prevalent in P6, C4, and R2. Facilities / infrastructure were mainly used in P8 and C3.

*Observation 2.2 (O2.2):* Information resources make up a high proportion in reactive practices.

Information was deemed the resource of highest proportion for reactive practices (C7, R1, and R5). These information resources must be turned into knowledge to have an added value. From this knowledge, further practices can be inferred.

*Observation 2.3 (O2.3):* Reactive practices cost the least (in these cases).

As the results suggest, most practices entail activities that are set up and maintained before their usage. The high proportion of proactive practice usage throughout the full cycle implies that proactive practices are an ongoing endeavor. Figure C-1 illustrates the mean allocated resource pool configuration for individual practices.

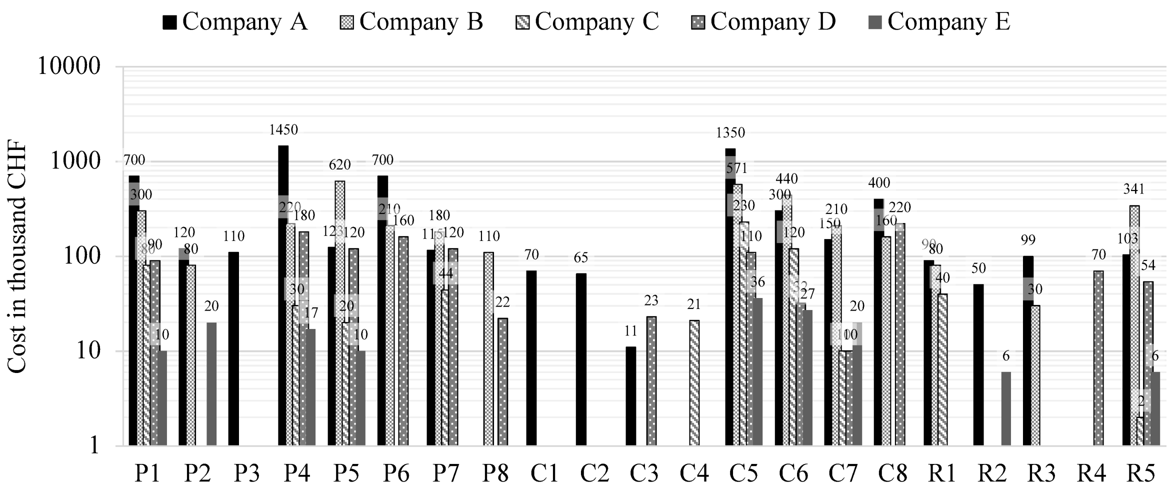


**Figure C-1.** Costs per practice for all companies (log scale), including mean allocated resource pools

## C.5 Discussion

Most prior research on SSRES costing has been focused on individual practices in specific company settings. In contrast, this study sought to take a holistic approach of breaking down practices into activities according to the PBV and applying the ABC to estimate expenditure on practices as a foundation for bottom-up cost aggregation. As PBV posits that the combination of rare, non-imitable practices explains the performance of a company, the resource allocation into SSRES activities, and therefore practices, is an important indicator of practice prioritization. While this study is not dedicated to linking SSRES and performance like the existing research (Alkalha et al., 2021), it identifies the relationships between the observations from the previous section and existing literature on intermediary resilience constructs. The expenditures into activities have an effect on higher-order resilience constructs, such as elements, capabilities, and strategies.

It does come as a surprise that the expenditure-to-PV ratios are extremely low across all companies (O1.1), considering the potential effect SSRES practices can have on company performance during and after a disruption. This is an indicator of the cost-effectiveness of SSRES practices. Going further, O1.2 puts company size and expenditure proportion in proactive practices into relation. One plausible explanation is the necessity of smaller companies (Companies C and E) to have cash reserves to expend when a disruption occurs, which in itself can be considered an additional SSRES practice (Hofmann et al., 2021; Melnyk et al., 2021). Furthermore, many concurrent practices incur costs during their setup and maintenance before the disruption. This is confirmed by Company C (see within case analysis). In general, this means that smaller companies should put more focus on building concurrent and reactive practices (I. Ali et al., 2017; Ates & Bititci, 2011). Meanwhile, many proactive practices are standard procedure in most companies (especially P4, P5, P6) and will need regular maintenance. On this note, O1.4 is an indicator that larger companies have more resources to build a diverse portfolio of SSRES practices. When the effectiveness of standard practices converges, additional expenditure into more practices becomes part of a diversification strategy (Grossman et al., 2021; Lin et al., 2021).

There are several researchers who posit that knowledge is one of the most valuable assets for SSRES (A. Ali et al., 2017; Blome et al., 2014; Melnyk et al., 2021; Zheng et al., 2011), as it drives decision-making for many other practices and capabilities. Some of this knowledge can be sourced internally through experienced employees, or externally through supply chain partners. O2.1 comments on the high proportion of personnel resources, which is highly dependent on the experience of the employees. If the experience level is high, activities within practices such as P4, P5, C7, C8, R1, and R5 can be executed in less amount of time. O2.2 confirms the importance of information assets, especially for reactive practices, coinciding with the relevance of post-disruption knowledge management as part of an SSRES capability (A. Ali et al., 2017).

In a recent study, Enthoven (2022) applied the PBV to SSRES and extended the concept to a self-learning feedback loop instead of a one-way practice-driven pipeline (Bromiley & Rau, 2014; Enthoven, 2022). Against this backdrop, this research has demonstrated that setup and maintenance activities require a lot more resources than actual usage activities. The continuous maintenance (i.e., CBM, UBM, or FBM) aids in keeping the self-learning loop upright. With every setup and maintenance step, both explicit and tacit knowledge increase and play a fundamental role in the selection and adaption of SSRES practices (Grant, 1996; Shafiee & Tabaeeian, 2021). Thereby, knowledge acts as a moderator and knowledge management as an overarching element of these practices. This is in accordance with Bromiley & Rau (2016), who state that "mediating and moderating variables are precisely how statistical models represent things not operating in isolation. As such, whether a practice benefits a firm or not depends on the specific circumstances of the firm" (Bromiley & Rau, 2016, p. 265).

## C.6 Conclusion

In this research, a multiple case study was conducted that identified 81 different activities across 21 SSRES practices for five MCs in the engineering, electronics, and automotive industries. These activities were classified as setup, maintenance, and usage activities. Cost estimations for the individual activities via frequency and expenditure per execution were collected and allocated to specific resource pools (RQ1). From the collected data, several insights from within-case and cross-case analysis could be derived, and the main resource levers could be identified. The research is grounded in the PBV that explains company performance through a combination of practices.

The research finds that main cost driver for SSRES practices for setting up, maintaining, and using SSRES practices across all phases is personnel. While personnel with more experience typically incur more cost per time unit, they generally lower the overall cost of some practices. Especially for reactive SSRES practices, information resources play a central role. These resources must be turned into knowledge, which enhances the capability to learn from the disruption through experience.

Furthermore, it was found that larger companies have a broader portfolio of SSRES practices and had proportionally spent more resources on proactive practices. This is partly due to the high length of the pre-disruption phase. Smaller companies require the cash reserves to leverage concurrent practices when a disruption impacts material flow.

Thus, RQ2 can be answered through the breakdown of SSRES strategies into capabilities, elements, practices, and activities, as well as the use of ABC as a bottom-up approach to put a price tag on these strategies. This study provides a perspective on operationalizing resilience and paves the way for future cost-effectiveness analyses. It sheds broad light on the incurred cost of resilience measures beyond simulation studies.

The exploratory nature of this study requires careful interpretation of the results. Although certain observations through patterns could be made, saturation of findings cannot be claimed due to the limited number of case companies in one geographic area. The selection of the case companies provided a deep insight into the SSRES practice and activities used, but additional interviews with companies that suffered major damages from a disruption could have proliferated the research.

The respective effectiveness of the practices, that is, the effect on a company's performance during the different phases of disruption, was not addressed. This study solely offers a way to operationalize the cost side of SSRES. The mapping of costs to practice effectiveness across the different capabilities entailed in SSRES is planned for future endeavors.

As the ABC found, high integration with the PBV yet requires highly detailed cost data and process understanding, however the case companies could only provide estimations, as none of the companies had systems in place to track overhead or process costs. Furthermore, every company had its own interpretation of the activities proposed, making cross-case analysis challenging. The large spread of responses was not surprising, as each company had its own processes for executing activities.

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# C.8 Appendix

**Table C-4.** Overview of all adopted practices with associated activity types, descriptions, and phases

| ID | SSRES practice | Type | Activity description | Activity phase pre | dur. | po. |
|---|---|---|---|---|---|---|
| **P1** | Upstream risk monitoring systems | S | Installation and deployment (entry of all suppliers, focus of geographic regions, notifications) | ✓ | | |
| | | FBM | Bug fixes and regular updates | ✓ | ✓ | ✓ |
| | | U | Regular check of current suppliers | ✓ | ✓ | ✓ |
| | | CBM | Addition and removal of suppliers in the system | ✓ | ✓ | ✓ |
| **P2** | Risk-sharing contractual agreements | S | Contract negotiation | ✓ | | |
| | | S | Contract drafting | | | |
| | | CBM | Contract updates / change of clauses | ✓ | ✓ | ✓ |
| | | U | Contract usage for delivery | ✓ | ✓ | ✓ |
| **P3** | Continuous improvement plans | S | Identification of opportunity for improvement | ✓ | | |
| | | S | Implementation & testing of improvement plan | ✓ | | |
| | | CBM | Optimization of improvement plan | ✓ | ✓ | ✓ |
| | | U | Usage of plan | ✓ | ✓ | ✓ |
| **P4** | Robust supplier selection / evaluation criteria | S | Setup of criteria guide | ✓ | | |
| | | CBM | Continuous development of the guide | ✓ | | |
| | | U | Application of the guide for supplier selection / evaluation | ✓ | ✓ | ✓ |
| | | CBM | Derivation of new criteria | ✓ | | ✓ |
| **P5** | Supplier training and development program | S | Analysis of supplier shortcomings with KPIs | ✓ | | |
| | | S | Development of plan to address issues (meetings, factory visit, training) | ✓ | | |
| | | S | Implementation of plan | ✓ | | |
| | | CBM | Tracking KPIs and updating plan | ✓ | ✓ | ✓ |
| **P6** | Supplier relationship management programs | S | Market research, internal requirements check | ✓ | | |
| | | S | Installation and deployment (segment supply base, KPIs, supplier strategies) | ✓ | | |
| | | FBM | Bug fixes and regular updates | ✓ | ✓ | ✓ |
| | | U | Usage of software (bidding, spend, performance) | ✓ | ✓ | ✓ |
| **P7** | Standardized supplier certification methods | S | Setup of requirements for supplier certification | ✓ | | |
| | | CBM | Continuous development of requirements | ✓ | | |
| | | U | Supplier certification for onboarding | ✓ | | |
| | | CBM | Derivation of new requirements | ✓ | ✓ | ✓ |
| **P8** | Incentive-aligning contracts (e.g., minimum order quantity) | S | Setup of contract requirements | ✓ | | |
| | | S | Contract negotiation | ✓ | | |
| | | CBM | Tracking of terms / renegotiation | ✓ | | |
| | | U | Usage of contract at purchase order | ✓ | | |
| **C1** | Insourcing production | S | Creation of production process requirements | ✓ | | |
| | | S | Setting up the production (sub)facility | ✓ | | |
| | | CBM | Preventive maintenance of production (sub)facility | ✓ | ✓ | |
| | | UBM | Regular maintenance of production (sub)facility | ✓ | | |
| | | U | Use of production (sub)facility | | ✓ | |
| **C2** | Usage of substitute parts in production | S | Definition of part requirements | ✓ | | |
| | | S | Setup sourcing for substitute parts | ✓ | | |
| | | S | Testing of substitute parts | ✓ | | |

| ID | SSRES practice | Type | Activity description | Activity phase pre | dur. | po. |
|---|---|---|---|---|---|---|
| | | CBM | Purchase / ensuring stock of substitute parts | ✓ | ✓ | |
| | | U | Usage of substitute parts in production | | ✓ | |
| **C3** | Flexible transportation volumes | S | Definition of relevant goods and transportation volumes | ✓ | | |
| | | S | Negotiation / agreement with LSP | ✓ | | |
| | | U | Flexible usage of transportation volumes | | ✓ | |
| **C4** | Transportation switching alternatives | S | Definition of delivery destinations / contract with LSP | ✓ | | |
| | | CBM | Continuous check of LSP's switching capacities | ✓ | ✓ | |
| | | U | Usage of transportation alternatives | | ✓ | |
| **C5** | Safety stock of critical items | S | Analysis of critical items needed | ✓ | | |
| | | S | Development of safety stock (size and place) | ✓ | | |
| | | CBM | Refilling of stock | ✓ | ✓ | |
| | | U | Usage of stock | | ✓ | |
| **C6** | Backup suppliers | S | Determination of suppliers / market research | ✓ | | |
| | | S | Supplier onboarding / certification | ✓ | | |
| | | CBM | Continuous check of supplier's production capacity | ✓ | ✓ | |
| | | U | Usage of backup supplier | | ✓ | |
| **C7** | Information sharing between supply chain partners | S | Definition of information requirements | ✓ | | |
| | | S | Setup and implementation of information channel | ✓ | | |
| | | U | Usage of information channel (reading / writing) | ✓ | ✓ | ✓ |
| | | UBM | Adaptation of channel / information requirements | ✓ | ✓ | |
| **C8** | Disruption task force team | U | Usage of task force / derivation of measures from task force | ✓ | ✓ | |
| | | S | Setup of disruption task force team | ✓ | ✓ | |
| | | S | Preparation of tools for the team | | ✓ | |
| | | CBM | Continuous upskilling of the team | | ✓ | |
| **R1** | Disruption recovery plan | S | Setup of a recovery plan and definition of desired effects | ✓ | ✓ | |
| | | S | Deployment of staff, materials, etc. for recovery plan | | | ✓ |
| | | U | Execution of recovery plan | | | ✓ |
| | | CBM | Adaptation of recovery plan | | | ✓ |
| **R2** | Increase in product prices | S | Identification of price increase opportunities / market leverage / calculation of effect on sales | | | ✓ |
| | | S | Communication to customers | | | ✓ |
| | | U | Renegotiation of contracts with customers | | | ✓ |
| **R3** | Decrease in production cost | S | Identification of cost reduction opportunities in production | | | ✓ |
| | | S | Derivation and execution of measures to reduce costs | | | ✓ |
| | | U | Increase of production | | | ✓ |
| **R4** | Prioritization of high-margin products in cases of limited supply | S | Definition of new production plan | ✓ | ✓ | ✓ |
| | | S | Implementation of new production plan | | | ✓ |
| | | CBM | Continuous recalculation of margin and adaptation of production plan | | | ✓ |
| **R5** | | S | Compilation of disruption relevant information | | | ✓ |

| ID | SSRES practice | Type | Activity description | Activity phase pre | dur. | po. |
|---|---|---|---|---|---|---|
| | Documentation and information sharing with suppliers and customers | S | Set up and implementation of information channel, incentivization of customers and suppliers to join | ✓ | ✓ | |
| | | U | Reading and writing of information in channel | | | ✓ |
| | | UBM | Continuous maintenance of information requirements / channel | | | ✓ |

# Curriculum Vitae

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## Education

| | |
|---|---|
| 09/2019-08/2022 | **UNIVERSITY OF ST. GALLEN**, St. Gallen, Switzerland<br>Ph.D. Candidate in Management |
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| 09/2019-08/2022 | **UNIVERSITY OF ST. GALLEN**, St. Gallen, Switzerland<br>Research Associate and Project Manager at the Institute of Supply Chain Management (ISCM-HSG) |
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| | |
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