The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/0144-3577.htm

The effect of production system characteristics on resilience capabilities: a multiple case study

Hendryk Dittfeld
Department of Supply Chain Finance, Windesheim University of Applied Sciences, Zwolle, the Netherlands, and
Dirk Pieter van Donk and Sam van Huet
Department of Operations, Faculty of Economics and Business, University of Groningen, Groningen, the Netherlands

Received 17 December 2021
Revised 6 March 2022
Accepted 6 April 2022

Abstract

Purpose – To date, the literature has usually assumed that a universal approach to resilience is appropriate in which different resilience capabilities are equally important for all organizations independent of contextual characteristics. In contrast this study investigates if production process characteristics affect resilience capabilities in terms of redundancy, flexibility, agility and collaboration.

Design/methodology/approach – An in-depth exploratory multiple case study was carried out in eight companies across different industries. Data were gathered through multiple interviews with key informants in each company.

Findings – The authors find differences in, and trade-offs between, resilience capabilities and practices related to redundancy, agility and collaboration induced by the different configurations of production system characteristics: especially between discrete and process industries. Further, a major influential characteristic is the production strategy employed (make-to-stock or make-to-order) which stresses or limits collaboration and redundancy.

Originality/value – This is one of the first studies to explore the effects of production system characteristics as a major contingency factor on the resilience capabilities of an organization. As such it provides valuable insights into the development of a more nuanced contingency approach to how organizations can build resilience and employ specific practices that fit their situation.

Keywords Resilience, Production system characteristics, Process industries, Discrete industries

Paper type Research paper

1. Introduction

It seems that organizational resilience differs across industries. For example, the automotive industry, often known for its ability to manage their supply chain (Azevedo *et al.*, 2013), has, since 2020, faced a lack of microchips with manufacturers still struggling to adapt their sourcing strategies to secure a supply of semiconductors, or to be flexible in their production system. In the dairy industry, FrieslandCampina (one of the world largest dairy producers) had to halt production due to a huge fire at a cheese factory causing considerable loss of raw

The authors acknowledge the assistance of J. Dummer, A. Schuurman and A. Bastinaansen in the data collection.

Funding: The study was partly funded by TKI Dinalog as part of the project "Ready for the Next Crisis" [2020-3-251 TKI].

materials (FrieslandCampina, 2014). While the automotive industry could increase inventory levels to ensure supply, the food processing industry seems limited in its ability to do so by the perishability of its raw materials (Van Kampen and Van Donk, 2014). These examples suggest production system characteristics have a role in the ability to be resilient which, in contrast to the role of suppliers (e.g. Son *et al.*, 2021), has hardly been investigated. As firms are often only able to build and employ resilience capabilities within the boundaries of their own organization (Duchek, 2020), it seems crucial to enhance our understanding of how production system characteristics, as an internal contingency, influence resilience capabilities. Exploring this relationship is the aim of the present paper.

With a growing awareness of resilience due to the ripple effects induced by COVID-19 and climate-related risks (Azadegan and Dooley, 2021), the developing stream of literature has focused on general antecedents, definitions and strategies of resilience (Christopher and Lee, 2004; Kamalahmadi and Parast, 2016; Ponomarov and Holcomb, 2009), suggesting a resilience that fits every context (Kochan and Nowicki, 2018). This paper defines an organization's resilience to supply chain disruptions as "the capability of the firm to be alert to, adapt to, and quickly respond to changes brought by a supply chain disruption." (Ambulkar *et al.*, 2015 p. 112). Despite early conceptual suggestions that resilience could be bound by a certain context, contrasting with a 'one size fits all' approach (Christopher and Peck, 2004), there is limited evidence for or attention to contextual fit (Kochan and Nowicki, 2018; Ali *et al.*, 2017). To date, research has paid attention to supply chain complexity (Brandon-Jones *et al.*, 2014; Wiedmer *et al.*, 2021), relationship characteristics (e.g. Bode *et al.*, 2011; Scholten and Schilder, 2015), firm size (Iborra *et al.*, 2020), socioeconomic factors (Tukamuhabwa *et al.*, 2017) and supply network structures (Kim *et al.*, 2015; Son *et al.*, 2021), but an organization's production system and its characteristics have been neglected. This is striking since the organizational resilience literature highlighting managing past disruptions has resulted in a contextualized set of capabilities (Ortiz-de-Mandojana and Bansal, 2016) rooted in the structure and technology of an organization (Duchek, 2020; Hillmann and Guenther, 2021). In general, there is abundant evidence that the effectiveness and implementation of supply chain management (SCM) practices depend on production and supply chain characteristics (Sousa and Voss, 2008). Specifically, the production system characteristics of process and of discrete industries have been shown to be rather different (e.g. Dennis and Meredith, 2000; Müller and Oehm, 2019) and to influence the applicability of various SCM and operations management (OM) concepts and practices such as lean (Lyons *et al.*, 2013; Zimmermann *et al.*, 2020), postponement (Van Hoek, 2001; Prataviera *et al.*, 2020) and sales and operations planning (Dittfeld *et al.*, 2021). Hence, there is a need to investigate if commonly applied resilience capabilities such as redundancy, collaboration, flexibility and agility (Tukamuhabwa *et al.*, 2015) can be equally applied in different configurations of production system characteristics (e.g. process versus discrete industries). Therefore, our main research question is: *How do production system characteristics influence the applicability of organizational resilience capabilities?* Given the exploratory nature of our research, we conducted a multiple case study among eight companies with a range of production system characteristics to investigate their influence on resilience capabilities.

This study makes several contributions. Foremost, our study provides evidence for trade-offs between resilience capabilities (e.g. Christopher and Peck, 2004; Purvis *et al.*, 2016), thereby providing much needed empirical nuances to the often suggested universal, equal and/or simultaneous applicability of resilience capabilities. In contrast to the classical trade-off between flexibility and redundancy (Sheffi and Rice Jr, 2005), we find that organizations make a deliberate choice between *agility* and redundancy. Specifically, our findings show that the trade-offs are strongly supported – if not driven – by production system characteristics embedded in the organizational context. As such, this study adds to the stream of research that provides insight into the contextual nature of OM and SCM practices (Sousa and Voss, 2008). Specifically, the study highlights how specific configurations of production system characteristics enable and limit the choice for specific resilience capabilities and practices. Process industry configurations mainly use redundancy and collaboration (at a less intense level), while discrete industry configurations tend to predominantly use collaborative and agile practices. While supply network characteristics (Brandon-Jones *et al.*, 2014; Bode *et al.*, 2011; Kim *et al.*, 2015) have been previously investigated, our research adds production system characteristics as an important factor in explaining how organizations build resilience. Moreover, our study provides not only insight into which production system characteristics especially determine resilience capabilities and practices but also which are less important, despite their claimed relevance. Finally, our study can help managers to better understand what are appropriate and useful practices in coping with supply chain disruptions, knowledge which is much needed in today's fast-changing business environments and complex supply chains (Bakshi and Kleindorfer, 2009).

2. Theoretical background

This section elaborates resilience, describes production system differences between process and discrete industries, which are then combined into a theoretical framework that guides our empirical study.

2.1 Organizational resilience to supply chain disruptions

Companies face many disruptions - i.e. unplanned and unanticipated events that disturb the movement of materials, goods and services (Craighead *et al.*, 2007) – which need to be addressed through resilience. Resilience and its associated capabilities can be understood from the organizational (Duchek, 2020; Hillmann and Guenther, 2021) and the supply chain resilience literature (Tukamuhabwa *et al.*, 2015; Scholten *et al.*, 2020). The organizational resilience literature highlights how capabilities are embedded in the social capital of a firm and depend on its past experiences (e.g. Duchek, 2020; Ortiz-de-Mandojana and Bansal, 2016). In the SCM literature, resilience capabilities are seen as formative elements (Scholten and Schilder, 2015) and refer to aspects such as redundancy, collaboration, visibility, agility, flexibility, supply chain risk culture and supply chain reengineering (e.g. Christopher and Peck, 2004; Jüttner and Maklan, 2011; Scholten and Schilder, 2015). Extensive literature reviews on supply chain resilience (e.g. Tukamuhabwa *et al.*, 2015; Ali *et al.*, 2017; Linnenluecke, 2017; Han *et al.*, 2020) that compare the definitions and measurements of the various capabilities used in the literature not only reveal considerable overlap but also differences. For example, Jüttner and Maklan (2011) see velocity and visibility as separate capabilities, whereas Wieland and Wallenburg (2012) combine them as agility. Capacity is mentioned as a capability by Pettit *et al.* (2013), but understood as part of redundancy in other studies (e.g. Ponis and Koronis, 2012). In order to avoid confusion and overlap, Tukamuhabwa *et al.* (2015) proposed four essential capabilities that cover the key strategies associated with building resilience. We follow their often cited and applied conceptualization and distinguish four well-defined capabilities: *flexibility, redundancy, collaboration* and *agility* (Jüttner and Maklan, 2011; Ponis and Koronis, 2012; Scholten and Schilder, 2015; Tukamuhabwa *et al.*, 2015; Ali *et al.*, 2017). Table 1 presents the definitions of each capability and the corresponding practices.

Researchers have debated the relative importance of, and relationships among, different capabilities: e.g. redundancy versus flexibility (Christopher and Peck, 2004; Ponomarov and Holcomb, 2009; Zsidisin and Wagner, 2010); collaboration as an enabler of flexibility and agility (Scholten and Schilder, 2015); or interactions between agility and flexibility (Purvis *et al.*, 2016; Tukamuhabwa *et al.*, 2015). While trade-offs between different capabilities are suggested, findings are inconclusive as to how and why. Kristianto *et al.* (2014), for example, concluded that

Capability	Definition	Practices
Redundancy	"Redundancy involves the strategic and selective use of spare capacity and inventory that can be invoked during a crisis to cope, e.g. with supply shortages or demand surges" (Tukamuhabwa *et al.*, 2015, p. 5604)	Excess capacity in production, multiple suppliers, safety stock (Ponis and Koronis, 2012; Tukamuhabwa *et al.*, 2015; Tang and Tomlin, 2008; Sodhi and Lee, 2007)
Collaboration	"Ability to work effectively with other entities for mutual benefit" (Pettit *et al.*, 2013, p. 49; see also Cao *et al.*, 2010)	Information-sharing, resource-sharing, forecast-sharing, collaborative forecasting, communications, postponement of orders, product life cycle management, risk sharing with partners (Cao *et al.*, 2010; Pettit *et al.*, 2013; Scholten and Schilder, 2015)
Flexibility	"The ability to take different positions to better respond to abnormal situations and rapidly adapt to significant changes in the supply chain" (Kamalahmadi and Parast, 2016, p. 122)	Postponement in production, flexible suppliers, flexible production and transportation processes, flexible decision processes (e.g. Tang and Tomlin, 2008; Pettit *et al.*, 2013)
Agility	"The ability of a supply chain to rapidly respond to change by adapting its initial stable configuration" (Wieland and Wallenburg, 2012, p. 302)	Business continuity planning, visibility, monitoring suppliers, crisis teams (Wieland and Wallenburg, 2012; Wagner and Neshat, 2012)

Source(s): Ali *et al.* (2017)

Table 1. Overview of resilience capabilities and corresponding practices

redundancy can also lead to being more flexible and therefore increases resilience, suggesting there is no trade-off at all. Nevertheless, considering the zone of balanced resilience (Pettit *et al.*, 2013) it seems that organizations need to make choices as to which capabilities to invest in to deal with vulnerabilities and that, such choices are context-dependent.

Resilience has been studied in many settings, focusing on differences in firm size (Iborra *et al.*, 2020), socioeconomic factors (Tukamuhabwa *et al.*, 2017), complexity (Brandon-Jones *et al.*, 2014; Wiedmer *et al.*, 2021), relationship nature (Bode *et al.*, 2011) or supply network structures (Kim *et al.*, 2015; Son *et al.*, 2021). The context-specificity of resilience is considered a fruitful avenue for future research (e.g. Linnenluecke, 2017; Pettit *et al.*, 2019) but mostly not explicitly included in the design of existing studies. Indirectly, context has been addressed though in-depth studies in different sectors such as healthcare (Scala and Lindsay, 2021) or critical infrastructures (Van den Adel *et al.*, 2021). However, there is a lack of empirical studies that address the impact of production systems despite anecdotic evidence of potential differences.

2.2 Production system characteristics

To characterize different production systems, we adopt some of the production system characteristics used to distinguish process and discrete industries (e.g. Müller and Oehm, 2019). From their list, we focus on (1) *product and process characteristics* as best representing the core technology that transforms input into output and (2) *planning and control characteristics* as proven relevant factors in earlier contingency-oriented research (Dennis and Meredith, 2000; Lyons *et al.*, 2013; Van Kampen and Van Donk, 2014). Together, the two groups capture characteristics that can help understand how resilience is shaped and limited in production companies. In discussing production system characteristics, the literature often contrasts process and discrete industries, which will be discussed individually below and compared in Table 2.

Process industries transform raw materials into products by combining ingredients according to formulas or recipes (Müller and Oehm, 2019), such as in food processing,

Key characteristics	Process industries	Discrete industries
Product and process		
Material flow	Divergent	Convergent
Distributed processes	Tightly coupled	Coordinated by the flow of discrete parts
Shelf-life constraints	Frequently perishable	Limited perishability
Raw material	Variable material grade	Predictable material grade
Yield variability	Sometimes high	Mostly low
Planning and control		
Production strategy	To stock	To order
Long term planning	Capacity	Product design
Planning focus	Utilization of capacity	Utilization of personnel
Starting point planning	Availability of capacity	Availability of material
Pausing production	Problematic (due to product losses)	Possible
Reworking faults	Rarely possible	Possible

Source(s): Based on Crama *et al.* (2001), Müller and Oehm (2019)

Table 2. Comparison of key characteristics in process and discrete industries

beverage, pharmaceutical and chemical companies (Panwar *et al.*, 2015). This often involves a divergent production process that typically only has a few raw materials that are transformed into a wide variety of products (Dennis and Meredith, 2000). In process industries, the raw materials are often perishable which has implications for inventory and production planning (Nahmias, 1982; Zhang *et al.*, 2020). In addition, there is often a point at which the production system changes from batch/continuous to discrete production (Van Donk, 2001; Pool *et al.*, 2011). In contrast, discrete industries use a combination of machines that work almost independently and are designed for a specific task (Müller and Oehm, 2019) to produce countable, distinguishable products that are often assembled based on a bill of materials (Lyons *et al.*, 2013). In these industries, value is mainly added by direct labor and one of the goals is to reduce the work-in-process. Often, discrete manufacturers focus on Just-In-Time (JIT) production and therefore material planning and reliable suppliers are critical (Crama *et al.*, 2001). Table 2 presents an overview of the key characteristics and the differences between these industries.

In practice, many organizations do not reflect one of the two archetypes summarized in Table 2 but combine aspects of both production systems or have both process and discrete elements (i.e. semi-process industries, Pool *et al.*, 2011). Such organizations are referred to as *mixed* industries in this study. As the literature does not guide us in how mixed industries combine key characteristics from both process and discrete industries, and there might be endless combinations, we focus on the relevance of the key characteristics of the two archetypes for resilience in our further conceptualization.

2.3 Research framework

Our aim is to investigate how characteristics of an organization's production system influence the applicability of resilience capabilities. Below, we explore how differences in "Product and Process" and "Planning and Control" characteristics between process and discrete industries, as being polar extremes on a spectrum of types, influence choices and options with the four key resilience capabilities. *Process industries* focus on high-capacity utilization and cope with high set-up and changeover times (Van Kampen and Van Donk, 2014) which result in limited or even an absence of redundancy (i.e. additional capacity). Such redundancy practices can be further limited (Scholten and Schilder, 2015) as the perishable nature of raw materials might limit buffering as an option, and by the high costs of production stops (Lee and Allwood, 2003). The need to process raw materials within their shelf-life constraints (Crama *et al.*, 2001; Van Kampen and Van Donk, 2014) might also limit flexibility. Here, a critical aspect, particularly for the food processing industries, is the vulnerability of their processes operating 24/7 when variability in raw material quality has to be considered (Dittfeld *et al.*, 2018; Donadoni *et al.*, 2019). Often, process industries depend on a few high-quality suppliers (Panwar *et al.*, 2015) which limit supply chain flexibility. However, having only a few suppliers results in long-term relationships with a high level of collaboration, and this promotes resilience (Pettit *et al.*, 2019). Finally, safety stock, flexible contracts, portfolio diversification and transportation planning have all been mentioned as approaches to enhance resilience in oil and gas supply chains, which are examples of typical non-food process industries (Urciuoli *et al.*, 2014). Based on the above, we might expect that characteristics of process industries favor collaboration but limit options to build redundancy and flexibility, although specific situations or configurations might influence their relevance.

Discrete industries are often characterized by convergent production systems where all the raw materials, subassemblies, and parts will be merged into one final product (Crama *et al.*, 2001). Further, discrete manufacturers can relatively easily, and at low cost, switch between producing different products, offering agility in the event of supplier disruptions, disrupted demands or volatility therein (Sodhi and Lee, 2007). Similarly, the option to pause production (Müller and Oehm, 2019) provides additional strategic and operational flexibilities which are crucial for building resilience in, for example, fashion and textile supply chains (Pal *et al.*, 2014). End-product diversity is high in a make-to-order environment and can be low in a make-to-stock setting (Müller and Oehm, 2019). For both strategies, on-time delivery of all components is critical, and this can be assured through extensive collaborative practices with all suppliers (Cao *et al.*, 2010). Typical discrete industries, such as the automotive one, are known for their flexible supply base and total supply chain visibility (Azevedo *et al.*, 2013), which enhances resilience. As such, discrete industries' characteristics might favor agility and seem to provide more options for organizations to build and employ flexibility and redundancy. However, specific real-life configurations could make other elements more important.

Finally, as already noted, for most industries, one cannot readily group all their characteristics under either process or discrete headings, making it even harder to envisage potential relationships between production system configurations and resilience capabilities. Therefore, we build empirically on the relationships depicted in Figure 1. The figure highlights that industries are positioned along the discrete process industry continuum which reflects their characteristics that in turn limit or enhance resilience.

3. Methodology

A multi-case study is an appropriate strategy for our research as our main research question – how production system characteristics influence the applicability of resilience capabilities – relates to a relatively new area of research (Eisenhardt and Graebner, 2007). Production system characteristics and resilience capabilities as key variables have been extensively but separately studied. Moreover, earlier studies indicate that context matters for how organizations build resilience capabilities (e.g. Brandon-Jones *et al.*, 2014). Despite this, there is a lack of recognized relationships and mechanisms that link the internal context of the production system to the different resilience capabilities. Consequently, we aim for theory elaboration (Ketokivi and Choi, 2014) to extend contingency research in the OM and SCM fields by specifically looking into the role of production system characteristics in building resilience. As such, an explorative multi-case study is considered appropriate to provide an in-depth insight into a context-specific phenomenon where the focus is on how, why, and what questions (Yin, 2009). Moreover, a multiple case-study enables one to explore a range of production processes, with different dominant characteristics, to facilitate generalizability

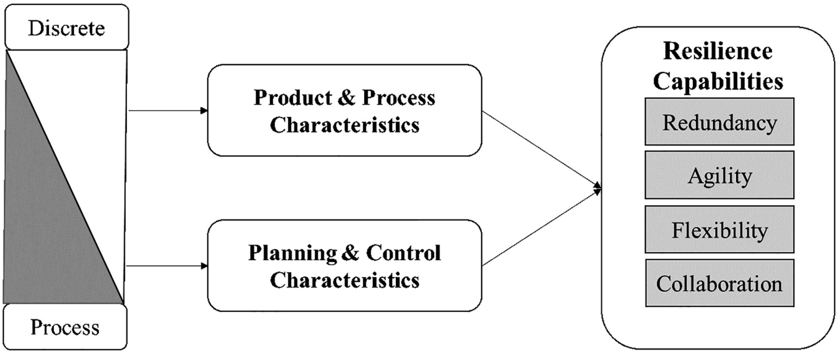


Figure 1.
Conceptual framework

and compare resilience capabilities across different settings (Gerring and McDermott, 2007) and increase external validity (Voss *et al.*, 2002). The unit of analysis is on the plant level. Adopting this unit of analysis provides an opportunity to examine individual businesses and compare different cases.

3.1 Case selection

In line with the research question, we selected production companies spread along the spectrum of process to discrete production. Starting from typical examples of both archetypes, we approached organizations from the automotive, chemical and food processing industries. In addition to being typical examples of either process (chemical, food) or discrete industries (automotive), Donadoni *et al.* (2019) have highlighted their vulnerability, making them also suitable from a resilience point of view. Further, to increase the variety as well as to cover the spectrum between the extreme archetypes, we approached a packaging manufacturer and a producer of health and hygiene products. Consequently, our selection included cases along the spectrum from pure process to discrete industries driven by the theoretical concerns elaborated in the theoretical background. Although theoretically driven, our selection could, as with many case studies, not be fully based on an in-depth knowledge of the production characteristics as they are hard to fully capture in advance. Therefore, our sample is to an extent also based on convenience sampling, driven by a willingness to participate. Despite these limitations, the eight cases cover a variety of industries and production system characteristics, making it a suitable sample for our aim (see Table 3).

All the cases are large production companies that operate globally with revenues between 0.5 and 20 billion Euros. As such, the sample is based on theoretical replication as we would expect that, driven by the different production characteristics, resilience capabilities might manifest themselves differently across the various industry types. To an extent, the sample also accommodates literal replication as similar industries might have similar characteristics and show a similar profile of resilience capabilities.

3.2 Case setting

A priori knowledge on the production system characteristics of the cases was combined with additional analysis to determine whether various characteristics could be considered as "discrete" or "process" directed. In this stage of the research, we assessed the production characteristics of each company through a number of well-established measures as per Table 2 (Dennis and Meredith, 2000; Van Donk, 2001). To capture the essence of "Product and Process Characteristics" we included material flow (convergent-divergent), shelf life and raw

Case, Industry	General information			Product & Process characteristics						Planning & Control characteristics						Cluster
				Material flow		Shelf-life constraints		Raw material		Planning focus		Production strategy		Pausing production		
	# Employees, Turnover in EUR	Interviewee position (Identifier), # Years experience	Length	Convergent	Divergent	Not perishable	Perishable	No variable raw material quality	Variable raw material quality	Labour intensive	Machine intensive	MTO	MTS	Pausing production possible	Pausing production not possible	
A: Automotive	6300, 6 billion	Director Logistic Operations (A1), 13 Manager Innovation & Improvement Operations (A2), 10	40:48:00 49:37:00	✓		✓		✓		✓		✓		✓		1 Discrete
B: Automotive	3000, 15 billion	Manager Material supply engineering (B1), 7 Supplier Quality Manager (B2), 4 Manager Logistics Supply (B3), 10	50:21:00 61:21:00 59:51:00	✓		✓		✓		✓		✓		✓		
C: Health & hygiene	9000, 13 billion	Sourcing Director (C1), 10 Manager Logistics Planner (C2), 7	48:30:00 46:35:00		✓	✓		✓			✓		✓		✓	2 Mixed
D: Chemical	1750, 8 billion	Supply Chain Planner (D1), 3 Supply Chain Planner (D2), 5	67:11:00 45:16:00		✓	✓		✓			✓		✓		✓	
E: Packaging manufacturer	6500, 1.2 billion	Supply Chain Manager Specialties (E1), 7 Supply Chain Manager (E2), 9	47:08:00 45:16:00		✓	✓		✓			✓		✓	✓		
F: Food processing	1600, 0.9 billion	Manager corporate Demand & Supply (F1), 9 Supply Chain Planner (F2), 3 Manager Logistics (F3), 10 Transport Manager (F4), 12	55:48:00 34:05:00 36:48:00 42:16:00		✓		✓		✓		✓		✓	✓		3 Process
G: Food processing	1300, 0.6 billion	Manager Supply Chain Management (G1), 7 Category Buyer Procurement (G2), 4	55:11:00 46:53:00		✓		✓		✓		✓		✓	✓		
H: Chemical	9000, 5 billion	Director Technology (H1), 12 Planning & Logistics Scheduler EMEA (H2), 10 Regional Supply Chain Manager (H3), 6 Supply Chain Director North & South America (H4), 12	61:59:00 52:44:00		✓	✓			✓		✓		✓		✓	

* grey columns indicate discrete industry charateristics and white columns process industry charateristics

Table 3.
General information on cases and interviewees

material variability; while "Planning and Control Characteristics" were measured by production strategy (Make to order [MTO] – Make to stock [MTS]), planning focus (machine versus labor) and production pausing options. This additional analysis confirmed our expectations of the food and the automotive industries being essentially process and discrete respectively. Against expectations, one of the organizations from the chemical industry was placed in the mixed industry because the point of discretization (Pool *et al.*, 2011) was early in the production process. Based on our assessments, all the cases were placed in one of three clusters as discussed below (see also Table 3).

3.2.1 Cluster 1: pure discrete industries. The first cluster consists of cases A and B which are both heavy vehicle manufacturers with production process characteristics that are purely discrete in nature. These companies apply JIT production strategies with very limited storage options on the assembly line, and even fewer for parts as these tend to be large and to some extent unique. The production systems both consist of convergent product flows where lots of different parts are assembled into a single end product. Since most of the value is added through labor, pausing production is possible but expensive given the large number of people employed.

3.2.2 Cluster 2: mixed industries. The companies in the second cluster (C, *D* and E) typically have a mix of characteristics that can be associated with both discrete and process industries. While these companies are predominantly process industry oriented, they do not have the typical perishability and variable raw material qualities, which makes them distinct from the pure process industries in cluster 3. Nevertheless, production is on an MTS basis with divergent material flows. In addition, in cases C and *D*, given the nature of their products, it was not possible pausing production without considerable problems related to material wastage and blocking the production system.

3.2.3 Cluster 3: pure process industries. The cases in the third cluster (F, *G* and H) can be seen as pure process industries. They apply an MTS strategy with divergent material flows. Also, cases F and *G* have to deal with perishability and variable raw material quality. Case H (chemicals) was connected to a network of other companies all receiving raw material by pipeline, and this impedes the ability to pause production due to the nature of the chemical processes involved.

3.3 Data collection

The main source of data in this study is 19 in-depth semi-structured interviews conducted in November 2019. Semi-structured interviews are able to capture most of the complexity and essentials present, while still allowing for some flexibility (Wilson, 2014; Yin, 2009). For each case, at least two knowledgeable interviewees, holding key positions in Operations, Production or SCM, were selected based on their experience with dealing with disruptions (see Table 3 for details). Having multiple interviewees for each case – each providing their own perspectives on specific events – enabled triangulation (Yin, 2009; Eisenhardt and Graebner, 2007) increasing the validity of our findings (Voss *et al.*, 2002). Each interview was conducted by two researchers to increase internal validity (Eisenhardt, 1989). Interviews followed an interview protocol to further boost reliability and validity (Yin, 2009), following the core concepts found in the literature with open-ended questions and probing to obtain detailed responses (see Appendix 1). Open questions (e.g. please describe a disruption and the organization's response) were used to prevent our theoretical ideas being imposed on the interviewees. At the same time, we used our list of resilience capabilities (based on Tukamuhabwa *et al.*, 2015) when probing to ensure that each capability was sufficiently covered during the interviews. Production characteristics were discussed to check the appropriateness of the *a-priori* determined characteristics that were based on previous literature as discussed above. Interviews were conducted at the premises of the interviewees who read and signed a consent form having been informed about the aim and background of the research. Interviews were recorded after permission was given. Finally, as outlined above, we checked the production characteristics and asked for additional information if needed. As a final step, the transcripts were sent back to the interviewees for confirmation of their accuracy to increase the construct validity (Yin, 2009).

3.4 Data analysis

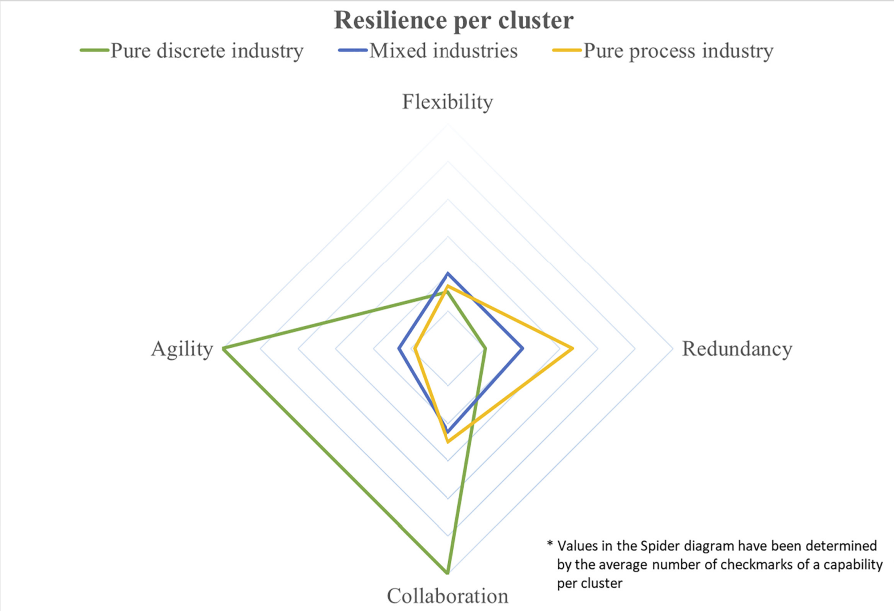
The transcribed interviews were coded using Atlas.ti software. As explained in the case setting section above, we categorized the eight cases into three clusters (see Table 3). These clusters were subsequently used as the starting point for cross-case comparisons.

To familiarize ourselves with the cases and to understand the main aspects of resilience in each case, summary reports were written as a first step in a within-case analysis. In the next step of the structured coding process, we selected quotes related to our constructs of interest. This predominantly deductive process was based on the theoretical underpinning of the study while being open to themes emerging from the data (Miles *et al.*, 2020). Such deductive coding fits with the aim of uncovering relationships between production system characteristics and resilience capabilities; rather than further extending the extensive knowledge on resilience capabilities and practices. After assigning first-order codes to these quotes, second-order codes were deductively established to further reduce the raw data (Miles *et al.*, 2020). The quotes were coded based on resilience practices (as per Table 1) to gain a fine-grained overview of the presence of the four resilience capabilities. In this step of the analysis, the second order codes, which represent the resilience practices as operationalized in our theoretical framing, were grouped together for each case to assess both the number of practices and their level. Here, for each practice, three levels were distinguished, represented by one, two or three checkmarks, based on the degree or frequency of that practice. For example, information sharing could range from little (√) through frequent (√√), to daily (√√√) (see findings, Figure 2). To clarify further, we use Case A as an example to explain how we arrived at three checkmarks in evaluating collaboration, using some illustrative quotes. Interviewee A1: *"That's why we want to have a good relationship when this is the case, you tell everything to each other, also when there are problems so we can solve it before real trouble happens"*. This is indicative of a high level of information sharing. Interviewee A2: *"We bring our supplier to our factory to show how we execute our development programs, etc. we train them on Six Sigma"*. This indicates a high level of resource-sharing. A second example comes from Case *D*, where a high level of safety stock was observed, which corresponds with the highest level of redundancy (three checkmarks): *"We defined stock targets for our fast-moving products, we want to have 80 to 90 days of stock" (D1).*

In the cross-case analysis, we first compared and aggregated the findings from the individual cases within each cluster to ensure internal validity. In this process, we generated an overview of the resilience practices and the production system characteristics per cluster. Juxtaposing the practices related to the four resilience capabilities with the specific production system characteristics allowed us to determine relationships among the main variables of this study. Appendix 2 provides an excerpt of the coding tree and illustrates the coding and juxtaposition of production system characteristics and agility for Cluster 2.

4. Results

Our findings indicate substantial differences in the deployment of resilience capabilities and associated practices among the purely discrete, mixed and pure process industries, indicating



Resilience capabilities and practices		***Cluster 1: Discrete***		***Cluster 2: Mixed***			***Cluster 3: Process***		
		A	***B***	**C**	**D**	**E**	**F**	**G**	**H**
Flexibility	Flexible order quantities	✓✓	✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓
	Postponement in production								
Redundancy	Excess capacity in production						✓	✓	
	Multiple suppliers	✓		✓		✓	✓✓✓	✓✓	✓
	Safety stock	✓	✓	✓✓	✓✓✓	✓✓	✓✓	✓✓	✓✓✓
Collaboration	Information-sharing	✓✓✓	✓✓✓	✓✓	✓	✓✓	✓✓	✓✓	✓✓
	Resource-sharing	✓✓✓	✓✓✓	✓✓		✓	✓✓	✓✓	
	Forecast-sharing	✓✓✓	✓✓✓		✓	✓	✓	✓	
Agility	Monitoring suppliers	✓✓✓	✓✓✓	✓		✓	✓	✓✓	
	Action plans	✓✓✓	✓✓✓	✓✓		✓			✓
	Crisis teams	✓✓✓	✓✓✓	✓					

Figure 2.
Resilience practices per cluster and per case

that production characteristics do have an effect. In particular, we see that the raw material quality and MTO variables relate to the degree of collaboration and agility. Additionally, our findings indicate that there are trade-offs between redundancy and agility. Below we show the extent to which the four capabilities are present in each cluster in order to be able to compare across cases and in doing so relate different production characteristics to the resilience capabilities.

4.1 Comparing resilience capabilities in three clusters

Following our scoring procedure, Figure 2 illustrates the resilience capabilities and associated practices for the three clusters and for each case. The cross-cluster analysis shows "Product and Process" and "Planning and Control" characteristics in relation to resilience capabilities. The impact of individual characteristics is determined in order to provide a detailed reflection on differences between the configurations of characteristics as embedded within the three clusters. Below we briefly elaborate on the clusters and the most prominent characteristics (Appendix 3 provides additional details).

In all the clusters, trade-offs are visible with high levels of practices on some capabilities and low levels on others. We see that the discrete cluster predominantly adopts agility and collaboration practices whereas the pure process cases focus on redundancy with only limited attention to agility practices. In discrete industries, redundancy is to an extent outsourced to suppliers which creates a need to focus on agility and collaboration to enable continuous production after a disruption. The mixed and process clusters show that building in redundancy reduces the need for agility, indicating that there are indeed trade-offs among the different resilience capabilities. At the same time, we can observe that the trade-offs are limited by characteristics of the production systems as further explored in discussing the results of the individual clusters.

In terms of production system characteristics, we see that differences such as (1) divergent vs. convergent material flow, (2) the presence of variability in the quality of raw material (measuring "Product and Process Characteristics"), and (3) make-to-stock vs. make-to-order (related to "Planning and Control Characteristics") influence the applicability of resilience capabilities. The need for agility in the discrete cluster is tied to the MTO production strategy adopted in combination with a convergent material flow, while redundancy in the process industry cluster is enabled through the divergent material flow in combination with an MTS production strategy. Furthermore, raw material variability drives the need to develop collaborative practices in the pure process industry cluster. It seems that both "Product and Process" and "Planning and Control" characteristics influence the presence of resilience capabilities. Given that the differences are largely embedded within the configurational settings of the clusters, we focus below on the individual clusters while paying attention within each cluster's findings to relevant individual characteristics.

4.1.1 Cluster 1 -pure discrete industry: collaboration and agility. The findings highlight the importance of both collaboration and agility for industries in this cluster. Both cases studied were highly engaged in collaborative activities with their suppliers given the need for reliable delivery from all their large supply bases (driven by the convergent product flow and MTO strategy). Collaboration is achieved through intensive information sharing, joint forecasting and resource sharing and transparency that makes the chain more resilient. As an interviewee stressed: *"It's mainly being transparent and proactive in your communication, it's really important that we receive a signal fast to act accordingly" (A2).* In addition, interviewees acknowledged that information sharing increases the ability to proactively avoid a potential disruption. Both companies are relatively large and have optimized processes, knowledge on which they share by actively adopting many resource-sharing activities. For example, *"We have a six-sigma organization and we also stimulate our suppliers to apply that knowledge, they can attend a course at our organization to improve their processes" (A1).* Our informants stressed that resource sharing is an important aspect of collaboration that provides mutual benefits. Accordingly, supplier development programs are established to increase delivery reliability. Finally, shared forecasts also play a role: *"We send forecasts for the next twelve months. For the first eighteen days of that, these are products that are already sold to our customers" (B3).*

We also found a high level of agility. Several interviewees stressed that the hundreds of suppliers have to deliver in a JIT mode (again driven by the MTO strategy and convergent product flow). Supplier monitoring practices, such as real-time insight into the status of orders and measuring the performance of suppliers, increase visibility. Here, electronic data interchange (EDI) and customized systems are used. The Case B company tracks performance in detail through a supplier rating program that is used by purchasing and logistics: *"Right now we have a tool on the supplier level and the parts level with which we can see if volumes increase or not. We also have a supplier rating, which we already calculate before ordering. We rate them on performance aspects such as delivery, communication, flexibility, and EDI reports" (B2).* Such continuous performance assessment provides visibility and also helps Case B to proactively prevent possible disruptions. In the event of disruptions, both companies adopt action plans and have task force teams. For example, *"We use an official letter with a signature for this, which includes the reason for the escalation and expectations of setting up an action plan" (B2).* Then, "*We form a task force team and then we look at what actions are necessary at that supplier" (B3) - a process that* guarantees responsiveness.

Flexibility practices are only employed to a limited extent as it is not easy to change the order of the unique products. Redundancy use is also limited with hardly any safety stock: *"We do not have much stock, even for our critical items we only have one and a half or two days of stock" (B2).* It seems that, in the discrete cluster, redundancy is in effect outsourced to their suppliers and this is linked to the MTO strategy.

4.1.2 Cluster 2 – mixed industry: redundancy. The companies in this cluster employ a variety of resilience practices with a focus on redundancy, using safety stock and, where possible, multiple suppliers. Holding safety stock is feasible due to a limited variety in products and/or raw materials as in Case D: "*In the first part of our overall process we can handle disruptions well by holding stock since we do not have associated risks" (D2).* Similarly, Cases C and *E* hold high safety stock levels to mitigate the risk of long lead-times for raw materials or based on past experiences of disruptions. As E2 explained: *"Based on that, you also try to create safety stocks, because you know that you are so dependent, and you have been disappointed in the past".* The divergent material flows mean that the risks associated with inventory are low as these materials are used for most products. For some companies in this cluster there are only a few suppliers available to provide specific raw materials. For example, in Case *D*, the company is dependent on two raw material suppliers, creating vulnerability: *"Last year, a fire took place at our main supplier, so they could not deliver, which caused our inventory level to drop really fast" (D1).* Incorporating redundancy through holding safety stock is strongly influenced by the large effects of material shortfalls that interrupt chemical processes (Cases C and D) and also linked to the "not possible to pause production" characteristic. Other resilience practices and strategies are moderately applied such as collaboration by forecast sharing: "*We monthly share our thirteen-week planning" (D1)*, and agility through monitoring: "*You actually want to have a dashboard with your critical suppliers, with a composed set of KPIs" (E1).*

4.1.3 Cluster 3 – pure process industry: redundancy and collaboration. The third cluster shows the highest level of redundancy. All cases build large safety stocks on the supply side to keep production running, a process eased by using only a few raw materials that are suitable for most products. As interviewees from Case F explained: *"You build up stock since you know you are going to sell it anyway" (F1)* and *"Most of the time we only need 80% of what we order, that way we create a buffer which we can also use for other products" (F2).* The underlying factor is, as in Cluster 2, the divergent nature of the material flow. Although the applicability of redundancy could potentially be affected and limited in Cases F and *G* as the raw material is perishable with a risk of large inventories becoming obsolescent, as in the mixed cluster, the limited number of raw materials used and their wide usability in production imposes few limitations on applying a redundancy strategy. Also, collaboration is important and several collaborative practices are employed. In particular, information sharing with critical suppliers is high (in Cases F and G) to deal with variable raw material quality. For example, Case F implemented a web application for suppliers to communicate changes, problems and potential disruptions regarding transportation. Similarly, Case *G* collaborates with its suppliers through a designated department that shares knowledge to improve quality: *"We try to help the suppliers to increase the output" (G2).* Case H connects in a rather different way to its supplier through a network of pipelines. As such, limited information sharing is needed in the short term as volumes are fixed within the limits of the pipelines. However, the need for information sharing over the longer term is high. Specifically, in the event of maintenance stops and other interruptions, the companies have to inform each other months in advance and, as a consequence: *"With all our partners that are coupled to us through pipes, we have frequent meetings" (H1).* Finally, in all the companies in this cluster, little is done in terms of developing agility as a response and, when disrupted, a reactive strategy is employed that favors the most important customers.

5. Discussion and theoretical implications

The goal of this study was to examine the influence of production system characteristics on the deployment of resilience capabilities. We find meaningful differences in the level and types of resilience capabilities and practices employed in three different configurations of production system characteristics. The flow of materials, the production strategy and the consistency of the raw material quality are important factors that enable or hinder specific resilience capabilities. Other characteristics such as perishability, options for pausing production and planning focus were found to be less influential in our sample. We also found a clear difference between pure discrete and pure process industries as to what capabilities are highly adopted and which ones only minimally. In our discussion below, we start by exploring the implications for resilience and the choices made concerning resilience capabilities and then elaborate on how production characteristics influence resilience strategies.

5.1 Balancing resilience capabilities

The literature has not addressed in detail the influence of external and internal contingency factors, such as the nature of and one's position in the supply chain, the type of relationship with suppliers, or the type of production processes, on resilience. Implicitly, the literature seems to suggest that, ideally, all four resilience capabilities can or should be deployed in order to become resilient. As such, the interrelationships or even trade-offs among the capabilities have been suggested but only vaguely linked to contextual attributes. Scholten and Schilder (2015) show that collaboration fills a central role, while Tukamuhabwa *et al.* (2015) suggest possible trade-offs between the four capabilities. Here, the trade-off between redundancy and flexibility has received most attention in the literature (Sheffi and Rice Jr., 2005; Kamalahmadi *et al.*, 2021). Interestingly, our results revealed that flexibility was not an important capability in any of our cases. This could perhaps be explained by the industrial context selected (automotive, chemical or food), in which all companies strive for high utilization. Therefore, we would encourage future research to study other discrete industries with, for example, pure job-shop processes to better understand the role of flexibility. While flexibility was not that significant in our findings, our analysis does suggest a trade-off between redundancy and agility (see Figure 2). However, a trade-off here is not an optional choice for managers but rather one driven and enabled by the specific characteristics of a company's production process. More specifically, discrete industries such as the automotive manufacturers in our sample have to rely on agility and collaboration as they produce to order and therefore monitor their large supply base to ensure timely provision of all the different parts needed for assembly. Further, these production characteristics make it costly to employ redundancy. Therefore, these organizations in effect outsource redundancy to suppliers, explaining the need for agility and collaboration. This implies that there are not only trade-offs among the capabilities adopted within an organization but also across the supply chain, adding empirical evidence to the work of Sá *et al.* (2020) who suggest that the position in the chain steers trade-offs and choices in building resilience. In process industries, organizations buffer their processes with safety stock, enabled by an MTS strategy and divergent product flow with limited input materials, even when the raw materials have a limited shelf life. Here redundancy is heavily employed, at the expense of agility, while collaborative practices are less critical but still present to a moderate extent. As such, we conclude that trade-offs do exist but need to be contextualized to understand the deliberate choices made. As such, our findings confront Kochan and Nowicki (2018) who examined resilience in various industries but did not consider the effect of their differences on resilience capabilities. Consequently, we posit:

Proposition 1. *Trade-offs in resilience capabilities and practices are influenced by contextual factors as embedded in the production system characteristics of a company.*

5.2 Production system characteristics and resilience capabilities

The fine-grained analysis undertaken enables us to understand the role of *individual* production system characteristics linked to both "process and product" (shelf life, raw material variability and material flow) and "planning and control" (MTO-MTS, planning focus and production pausing options) in shaping resilience.

Our findings suggest that companies that are more focused on satisfying the customized demands of their customers use an MTO production strategy and invest in tuning their supply to production, which requires a more intense flow of information with their suppliers through extensive ICT usage (Vanpoucke and Ellis, 2020). Investing in supplier development encourages suppliers to invest in their own product quality and contingency plans to be able to deal quickly with their own disruptions. These measures are often also needed because inventory levels are low due to an MTO strategy combined with many unique parts obtained from single sources. Interestingly, such a dependency is also visible in the provision of raw materials with only a limited number of suppliers, especially in the case of natural materials where it is not possible to fully control the quality (Davis *et al.*, 2021). Here, manufacturers similarly seek collaboration through information sharing, joint ICT and quality improvement (Scholten and Schilder, 2015). Together these practices provide a basis of collaboration that aims to prevent disruptions and certainly helps build resilience. Hence, we posit:

Proposition 2a. *Collaborative and agile practices are specifically enabled by and most prominent companies, characterized by an MTO strategy and high dependence on suppliers through single sourcing or raw material variability.*

Somewhat similarly, our findings suggest that the adoption of redundancy practices, and specifically of holding inventories, is limited to certain production settings (Sheffi, 2019). In general, it is remarkable how little spare capacity is observed. With respect to redundancy in the form of an inventory of incoming goods, the production strategy and the associated nature of the products (being either more customized or generic) determines if inventories are potentially feasible. Contrary to our expectations, the analysis shows that process industries invest more in building in redundancy than discrete industries. The counterintuitive high level of redundancy in process industries primarily stems from redundancy created upstream (with multiple suppliers, safety stock) to guarantee that production continues with a high utilization factor. Specifically, we see that MTS processes with largely generic raw materials can buffer by establishing inventories as a means to be resilient, unlike MTO companies whose suppliers deliver customized parts (Peeters and Van Ooijen, 2020). Hence, we formulate our next proposition as:

Proposition 2b. A MTS policy enables the application of redundancy, whereas MTO inhibits redundancy.

Propositions 2a and 2b together provide refined insights and arguments in the discussion as to when and how companies respond to disruptions. Here, Bode *et al.* (2011) focused on buffering and bridging approaches driven by internal and external factors. We add the production strategy employed as an important additional factor that drives the choice between those two (here labeled as redundancy and collaboration). Nevertheless, in line with Bode *et al.* (2011), it is clear that the collaborative practices identified in our study are linked to dependency (as on a single source) and trusted relations.

As a final discussion point, and in contrast to our *a priori* theoretical expectations, we found that some of our production process characteristics have little effect on resilience capabilities. Specifically, although we had expected a limited shelf life to be a restricting factor, this turned out to be less significant, and similarly relying on a continuous processes was also less influential than expected (Van Kampen and Van Donk, 2014; Lee and Allwood, 2003). Regarding the latter, we saw that stopping production was seen by all companies as something to be avoided, with the costs of interruptions seen as unduly high whatever the production system. This probably explains why this factor does not have a clear influence on the choices made over resilience strategies and practices. Companies having to deal with limited shelf lives still opted to hold some buffers and seemed able to manage these effectively.

6. Conclusions

Our research has led to several important findings regarding the influence of production system characteristics on the applicability of resilience capabilities. First, we found that configurations of production system characteristics impose important boundary conditions on the trade-offs between the various resilience capabilities. Second, we saw that certain characteristics indeed favor or hinder the applicability of each of the four capabilities, and also that not all the characteristics are equally important. Below, we provide some insights from our findings for managers and discuss potential limitations and future research opportunities.

6.1 Managerial implications

Our findings suggest that resilience is shaped by, and needs to be tuned to, the production context. Specific production configurations provide a basis for or limit the use of specific capabilities and practices. Managers need to be aware of their own situation when considering how to prepare should they be confronted with disruptions. Specifically, for MTO and MTS production approaches rather different approaches are needed, with the former demanding agility and the latter redundancy in order to build resilience. As such, our study provides guidance when making choices and shows that not all capabilities and associated practices can be employed in all situations.

6.2 Limitations and suggestions for further research

As with all studies, ours has its limitations. Firstly, our sample is limited and other industries such as retail, textile and electronics (Pal *et al.*, 2014) might indeed show different patterns and relationships. Nevertheless, our spread of companies and the range of characteristics included have enabled us to also relate production characteristics to resilience, potentially giving our findings a general validity. Despite this, we would encourage further research across a wider variety of cases in a diversity of industries and production situations. In particular, the cluster we labeled as mixed industries provides options for further research by extending the focus on either pure process or purely discrete industries to include more organizations between these extremes. By including organizations from multiple industries and using validated scales to measure resilience capabilities (e.g. Pettit *et al.*, 2013), future research could support or nuance the insights developed in this study. Such research could also help to further explore and generalize our findings, as represented in the propositions, on specific characteristics and their relationship with specific resilience practices. For example, to test Proposition 1, a large-scale survey could establish statistical support for the proposed influence of internal contingencies on trade-offs among resilience capabilities.

Our research has largely focused on production-related characteristics while other factors are known to be relevant, such as complexity (Brandon-Jones *et al.*, 2014) and internal and external factors (Bode *et al.*, 2011), which might intervene in or dominate the characteristics we considered. Hence, we would encourage researchers to investigate the mutual influences of such diverse factors. Such research could also extend to the demand side of companies (Van Hoek, 2020) to address our limitation in focusing only on internal and supply-side issues. Further, our focus was on the plant level of organizations, thereby ignoring options for resilience across the chain or in networks of organizations (Scholten *et al.*, 2020; Sá *et al.*, 2020). This is another area where research could explicitly consider network characteristics and plant characteristics jointly.

A final direction for future research would be to incorporate more explicitly the effectiveness and efficiency of the different practices given that our focus was on what is done without assessing the effectiveness or costs. Here, a survey instrument could further verify our propositions and draw conclusions based on robust statistical inference.

References

Ali, A., Mahfouz, A. and Arisha, A. (2017), "Analysing supply chain resilience: integrating the constructs in a concept mapping framework via a systematic literature review", *Supply Chain Management: An International Journal*, Vol. 22 No. 1, pp. 16-39.

Ambulkar, S., Blackhurst, J. and Grawe, S. (2015), "Firm's resilience to supply chain disruptions: scale development and empirical examination", *Journal of Operations Management*, Vol. 33 No. 1, pp. 111-122.

Azadegan, A. and Dooley, K. (2021), "A typology of supply network resilience strategies: complex collaborations in a complex world", *Journal of Supply Chain Management*, Vol. 57 No. 1, pp. 17-26.

Azevedo, S.G., Govindan, K., Carvalho, H. and Cruz-Machado, V. (2013), "Ecosilient Index to assess the greenness and resilience of the upstream automotive supply chain", *Journal of Cleaner Production*, Vol. 56, pp. 131-146.

Bakshi, N. and Kleindorfer, P. (2009), "Coopetition and investment for supply-chain resilience", *Production and Operations Management*, Vol. 18 No. 6, pp. 583-603.

Bode, C., Wagner, S.M., Petersen, K.J. and Ellram, L.M. (2011), "Understanding responses to supply chain disruptions: insights from information processing and resource dependence perspectives", *Academy of Management Journal*, Vol. 54 No. 4, pp. 833-856.

Brandon-Jones, E., Squire, B., Autry, C.W. and Petersen, K.J. (2014), "A contingent resource-based perspective of supply chain resilience and robustness", *Journal of Supply Chain Management*, Vol. 50 No. 3, pp. 55-73.

Cao, M., Vonderembse, M.A., Zhang, Q. and Ragu-Nathan, T.S. (2010), "Supply chain collaboration: conceptualisation and instrument development", *International Journal of Production Research*, Vol. 48 No. 22, pp. 6613-6635.

Christopher, M. and Lee, H. (2004), "Mitigating supply chain risk through improved confidence", *International Journal of Physical Distribution and Logistics Management*, Vol. 34 No. 5, pp. 388-396.

Christopher, M. and Peck, H. (2004), "Building the resilient supply chain", *International Journal of Logistics Management*, Vol. 15 No. 2, pp. 1-13.

Craighead, C.W., Blackhurst, J., Rungtusanatham, M.J. and Handfield, R.B. (2007), "The severity of supply chain disruptions: design characteristics and mitigation capabilities", *Decision Sciences*, Vol. 38 No. 1, pp. 131-156.

Crama, Y., Pochet, Y. and Wera, Y. (2001), "A discussion of production planning approaches in the process industry", Core Discussion Paper, 01/42 UCL, Belgium.

Davis, K.F., Downs, S. and Gephart, J.A. (2021), "Towards food supply chain resilience to environmental shocks", *Nature Food*, Vol. 2, pp. 54-65.

Dennis, D. and Meredith, J. (2000), "Empirical analysis of process industry transformation systems", *Management Science*, Vol. 46 No. 8, pp. 1085-1099.

Dittfeld, H., Scholten, K. and Van Donk, D.P. (2018), "Burden or blessing in disguise: interactions in supply chain complexity", *International Journal of Operations and Production Management*, Vol. 38 No. 2, pp. 314-332.

Dittfeld, H., Scholten, K. and Van Donk, D.P. (2021), "Proactively and reactively managing risks through sales and operations planning", *International Journal of Physical Distribution and Logistics Management*, Vol. 51 No. 6, pp. 566-584.

Donadoni, M., Roden, S., Scholten, K., Stevenson, M., Caniato, F., Van Donk, D.P. and Wieland, A. (2019), *The Future of Resilient Supply Chains*, Springer International Publishing, Cham.

Duchek, S. (2020), "Organizational resilience: a capability-based conceptualization", *Business Research*, Vol. 13 No. 1, pp. 215-246.

Eisenhardt, K.M. (1989), "Building theories from case study research", *The Academy of Management Review*, Vol. 14 No. 4, pp. 532-550.

Eisenhardt, K.M. and Graebner, M.E. (2007), "Theory building from cases: opportunities and challenges", *Organizational Research Methods*, Vol. 50 No. 1, pp. 25-32.

FrieslandCampina (2014), "Brand bij FrieslandCampina cheese gerkesklooster", available at: https://www.frieslandcampina.com/nl/nieuws/2014-07-29-brand-bij-frieslandcampina-cheese-gerkesklooster/.

Gerring, J. and McDermott, R. (2007), "An experimental template for case study research", *American Journal of Political Science*, Vol. 51 No. 3, pp. 688-701.

Han, Y., Chong, W.K. and Li, D. (2020), "A systematic literature review of the capabilities and performance metrics of supply chain resilience", *International Journal of Production Research*, Vol. 58 No. 15, pp. 4541-4566.

Hillmann, J. and Guenther, E.M. (2021), "Organizational resilience: a valuable construct for management research?", *International Journal of Management Reviews*, Vol. 23 No. 1, pp. 7-44.

Iborra, M., Safón, V. and Dolz, C. (2020), "What explains the resilience of SMEs? Ambidexterity capability and strategic consistency", *Long Range Planning*, Vol. 53 No. 6, pp. 1-15.

Jüttner, U. and Maklan, S. (2011), "Supply chain resilience in the global financial crisis: an empirical study", *Supply Chain Management: An International Journal*, Vol. 16 No. 4, pp. 246-259.

Kamalahmadi, M. and Parast, M.M. (2016), "A review of the literature on the principles of enterprise and supply chain resilience: major findings and directions for future research", *International Journal of Production Economics*, Vol. 171, pp. 116-133.

Kamalahmadi, M., Shekarian, M. and Parast, M.M. (2021), "The impact of flexibility and redundancy on improving supply chain resilience to disruptions", *International Journal of Production Research*, Vol. 60 No. 6, pp. 1992-2020.

Ketokivi, M. and Choi, T. (2014), "Renaissance of case research as a scientific method", *Journal of Operations Management*, Vol. 32 No. 5, pp. 232-240.

Kim, Y., Chen, Y. and Linderman, K. (2015), "Supply network disruption and resilience: a network structural perspective", *Journal of Operations Management*, Vol. 33 No. 1, pp. 43-59.

Kochan, C.G. and Nowicki, D.R. (2018), "Supply chain resilience: a systematic literature review and typological framework", *International Journal of Physical Distribution and Logistics Management*, Vol. 48 No. 8, pp. 842-865.

Kristianto, Y., Gunasekaran, A., Helo, P. and Hao, Y. (2014), "A model of resilient supply chain network design: a two-stage programming with fuzzy shortest path", *Expert Systems with Applications*, Vol. 41 No. 1, pp. 39-49.

Lee, W.L. and Allwood, J.M. (2003), "Lean manufacturing in temperature dependent processes with interruptions", *International Journal of Operations and Production Management*, Vol. 23 Nos 11-12, pp. 1377-1400.

Linnenluecke, M. (2017), "Resilience in business and management research: a review of influential publications and a research agenda", *International Journal of Management Reviews*, Vol. 19, pp. 4-30.

Lyons, A.C., Vidamour, K., Jain, R. and Sutherland, M. (2013), "Developing an understanding of lean thinking in process industries", *Production Planning and Control*, Vol. 24 No. 6, pp. 475-494.

Miles, M.B., Huberman, A.M. and Saldaña, J. (2020), *Qualitative Data Analysis: A Methods Sourcebook*, 4th ed., SAGE Publications, Thousand Oaks.

Müller, R. and Oehm, L. (2019), "Process industries versus discrete processing: how system characteristics affect operator tasks", *Cognition, Technology and Work*, Vol. 21 No. 2, pp. 337-356.

Nahmias, S. (1982), "Perishable inventory theory: a review", *Operations Research*, Vol. 30 No. 4, pp. 680-708.

Ortiz-de-Mandojana, N. and Bansal, P. (2016), "The long-term benefits of organizational resilience through sustainable business practices", *Strategic Management Journal*, Vol. 37 No. 8, pp. 1615-1631.

Pal, R., Torstensson, H. and Mattila, H. (2014), "Antecedents of organizational resilience in economic crises — an empirical study of Swedish textile and clothing SMEs", *International Journal of Production Economics*, Vol. 147, pp. 410-428.

Panwar, A., Nepal, B.P., Jain, R. and Rathore, A.P.S. (2015), "On the adoption of lean manufacturing principles in process industries", *Production Planning and Control*, Vol. 26 No. 7, pp. 564-587.

Peeters, K. and Van Ooijen, H. (2020), "Hybrid make-to-stock and make-to-order systems: a taxonomic review", *International Journal of Production Research*, Vol. 58 No. 15, pp. 4659-4688.

Pettit, T.J., Croxton, K.L. and Fiksel, J. (2013), "Ensuring supply chain resilience: development and implementation of an assessment tool", *Journal of Business Logistics*, Vol. 34 No. 1, pp. 46-76.

Pettit, T.J., Croxton, K.L. and Fiksel, J. (2019), "The evolution of resilience in supply chain management: a retrospective on ensuring supply chain resilience", *Journal of Business Logistics*, Vol. 40 No. 1, pp. 56-65.

Ponis, S.T. and Koronis, E. (2012), "Supply chain resilience? Definition of concept and its formative elements", *The Journal of Applied Business Research*, Vol. 28 No. 5, pp. 921-935.

Ponomarov, S.Y. and Holcomb, M.C. (2009), "Understanding the concept of supply chain resilience", *The International Journal of Logistics Management*, Vol. 20 No. 1, pp. 124-143.

Pool, A., Wijngaard, J. and Van Der Zee, D.J. (2011), “Lean planning in the semi-process industry, a case study”, *International Journal of Production Economics*, Vol. 131, pp. 194-203.

Prataviera, L.B., Perotti, S., Melacini, M. and Moretti, E. (2020), “Postponement strategies for global downstream supply chains: a conceptual framework”, *Journal of Business Logistics*, Vol. 41 No. 2, pp. 94-110.

Purvis, L., Spall, S., Naim, M. and Spiegler, V. (2016), “Developing a resilient supply chain strategy during ‘boom’ and ‘bust”, *Production Planning and Control*, Vol. 27 Nos 7-8, pp. 579-590.

Sá, M.M.d., Miguel, P.L.d.S., Brito, R.P.d. and Pereira, S.C.F. (2020), “Supply chain resilience: the whole is not the sum of the parts”, *International Journal of Operations and Production Management*, Vol. 40 No. 1, pp. 92-115.

Scala, B. and Lindsay, C.F. (2021), “Supply chain resilience during pandemic disruption: evidence from healthcare”, *Supply Chain Management: An International Journal*, Vol. 26 No. 6, pp. 672-688.

Scholten, K. and Schilder, S. (2015), “The role of collaboration in supply chain resilience”, *Supply Chain Management: An International Journal*, Vol. 20 No. 4, pp. 471-484.

Scholten, K., Stevenson, M. and van Donk, D.P. (2020), “Dealing with the unpredictable: supply chain resilience”, *International Journal of Operations and Production Management*, Vol. 40 No. 1, pp. 1-10.

Sheffi, Y. (2019), “Preparing for the worst”, in Zsidisin, G. and Henke, M. (Eds), *Revisiting Supply Chain Risk. Springer Series in Supply Chain Management*, Springer, Cham.

Sheffi, Y. and Rice, J.B. Jr (2005), “A supply chain view of the resilient enterprise”, *MIT Sloan Management Review*, Vol. 47 No. 1, pp. 41-48.

Sodhi, M.S. and Lee, S. (2007), “An analysis of sources of risk in the consumer electronics industry”, *Journal of the Operational Research Society*, Vol. 58 No. 11, pp. 1430-1439.

Son, B.G., Chae, S. and Kocabasoglu-Hillmer, C. (2021), “Catastrophic supply chain disruptions and supply network changes: a study of the 2011 Japanese earthquake”, *International Journal of Operations and Production Management*, Vol. 41 No. 6, pp. 781-804.

Sousa, R. and Voss, C.A. (2008), “Contingency research in operations management practices”, *Journal of Operations Management*, Vol. 26 No. 6, pp. 697-713.

Tang, C. and Tomlin, B. (2008), “The power of flexibility for mitigating supply chain risks”, *International Journal of Production Economics*, Vol. 116 No. 1, pp. 12-27.

Tukamuhabwa, B.R., Stevenson, M., Busby, J. and Zorzini, M. (2015), “Supply chain resilience: definition, review and theoretical foundations for further study”, *International Journal of Production Research*, Vol. 53 No. 18, pp. 5592-5623.

Tukamuhabwa, B., Stevenson, M. and Busby, J.S. (2017), “Supply chain resilience in a developing country context: a case study on the interconnectedness of threats, strategies, and outcomes”, *Supply Chain Management: An International Journal*, Vol. 22 No. 6, pp. 486-505.

Urciuoli, L., Mohanty, S., Hintsa, J. and Boekesteijn, E.G. (2014), “The resilience of energy supply chains: a multiple case study approach on oil and gas supply chains to Europe”, *Supply Chain Management: An International Journal*, Vol. 19 No. 1, pp. 46-63.

Van den Adel, M.J., de Vries, T.A. and van Donk, D.P. (2021), “Resilience in interorganizational networks: dealing with day-to-day disruptions in critical infrastructures”, *Supply Chain Management: An International Journal*, Vol. 27 No. 7, pp. 64-78.

Van Donk, D.P. (2001), “Make to stock or make to order: the decoupling point in the food processing industries”, *International Journal of Production Economics*, Vol. 69, pp. 297-306.

Van Hoek, R.I. (2001), “Rediscovery of postponement a literature review and directions for research”, *Journal of Operations Management*, Vol. 19 No. 2, pp. 161-184.

Van Hoek, R.I. (2020), “Research opportunities for a more resilient post-COVID-19 supply chain – closing the gap between research findings and industry practice”, *International Journal of Operations and Production Management*, Vol. 40 No. 4, pp. 341-355.

Van Kampen, T. and Van Donk, D.P. (2014), "Coping with product variety in the food processing industry: the effect of form postponement", *International Journal of Production Research*, Vol. 52 No. 2, pp. 353-367.

Vanpoucke, E. and Ellis, S.C. (2020), "Building supply-side resilience – a behavioural view", *International Journal of Operations and Production Management*, Vol. 40 No. 1, pp. 11-33.

Voss, C., Tsikriktsis, N. and Frohlich, M. (2002), "Case research in operations management", *International Journal of Operations and Production Management*, Vol. 22 No. 2, pp. 195-219.

Wagner, S.M. and Neshat, N. (2012), "A comparison of supply chain vulnerability indices for different categories of firms", *International Journal of Production Research*, Vol. 50 No. 11, pp. 2877-2891.

Wiedmer, R., Rogers, Z.S., Polyviou, M., Mena, C. and Chae, S. (2021), "The dark and bright sides of complexity: a dual perspective on supply network resilience", *Journal of Business Logistics*, Vol. 42 No. 3, pp. 336-359.

Wieland, A. and Wallenburg, C.M. (2012), "Dealing with supply chain risks: linking risk management practices and strategies to performance", *International Journal of Physical Distribution and Logistics Management*, Vol. 42 No. 10, pp. 887-905.

Wilson, C. (2014), *Interview Techniques for UX Practioners: A User-Centered Design Method*, Morgan Kaufmann, Waltham, MA.

Yin, R.K. (2009), *Case Study Research: Design and Methods*, Sage Publications, Thousand Oaks, CA.

Zhang, H., Zhang, J. and Zhang, R.Q. (2020), "Simple policies with provable bounds for managing perishable inventory", *Production and Operations Management*, Vol. 29 No. 11, pp. 2637-2650.

Zimmermann, R., Ferreira, L.M.D. and Moreira, A.C. (2020), "An empirical analysis of the relationship between supply chain strategies, product characteristics, environmental uncertainty and performance", *Supply Chain Management: An International Journal*, Vol. 25 No. 3, pp. 375-391.

Zsidisin, G.A. and Wagner, S.M. (2010), "Do perceptions become reality? The moderating role of supply chain resiliency on disruption occurrence", *Journal of Business Logistics*, Vol. 31 No. 2, pp. 1-20.

Corresponding author
Dirk Pieter van Donk can be contacted at: d.p.van.donk@rug.nl

Appendix 1

Interview protocol

The interviewees will be asked to describe general characteristics of the firm, product and processes and then to relate these to various disruptions (large/small, successful/less successful response). Finally, a checklist is provided for in-depth follow-up questions if needed.

Supply Chain Resilience

(1) Please describe a recent supply chain disruption.
- Large
- Small

(2) How did the organization deal with this disruption?
- Would you consider this to be a successful response? Why?
- Would you consider this to be an unsuccessful response? Why?

(3) Which elements were important here?
(To find which strategies are important and which is applied in SCRES).
- Flexibility
- Redundancy
- Collaboration
- Agility

(4) Was this a proactive or reactive strategy?

(Checklist for further details)

Collaboration

(1) On what basis are you in contact with your suppliers/buyers?
(2) What type of information is shared?
(3) Can you describe how you collaborate with each other (frequency, intensity, etc.)?
(4) How do you distinguish your collaboration with different suppliers/buyers?

Agility

(1) How would you describe the visibility of the supply chain?
(2) Do you/other members have access to the information required so you can respond to a disruption?
(3) Were potential risks along the chain identified easily and shared among members?
(4) Were you able to respond quickly during recent disruptions?

Redundancy

(1) Do you use safety stocks for certain materials? Based on what criteria?
(2) Do you have multiple suppliers for certain products?
(3) Is there overcapacity in certain situations?

(4) Do you use buffers in the production process? What type(s)?

(5) Are there particular reasons for having different production facilities? Why?

Flexibility

(1) Can you easily rearrange your capacity if needed?

(2) Can your supplier easily rearrange capacity?

(3) Can you respond quickly to changing needs?

Production system characteristics (Most of the aspects known in advance and from general questions)

(1) Do you have to take the perishability of raw materials into account?

(2) Do you have to take the variability of raw materials into account?

(3) From what moment in production does the process become discrete? What are the consequences on resilience?

(4) Is it possible to pause production? (Without a loss of products)

Appendix 2

Table A1.
Coding tree excerpt

Perishable	MTO / MTS	Material flow	Cluster	Data reduction (1st order quotes)	Descriptive code (2nd order quotes)	Resilience practice	Resilience Capability
Not perishable	MTS	Divergent	Cluster 2	Yes, we have 'secure supply' and contingency plans and we try to get our demand from that one supplier. (C1)	Action plans	Business continuity planning	Agility
Not perishable	MTS	Divergent	Cluster 2	Or you could bring together all stakeholders within the organization. What we did that moment.. We have this purchasing pillar within our organization, responsible for purchasing goods. We invited the responsible person for purchasing, we asked him to create insights about all stakeholders within our organization, purchasing from this specific supplier. (E2)	Action plans		
Not perishable	MTS	Divergent	Cluster 2	For each problem we have some contingency plan. For example, if here at the production site something happens with the cans, then we can also transfer to a different location. So within the organization, we have a backup. We cannot do it for every customer, but for a major part we can. (E1)	Action plans		
Not perishable	MTS	Divergent	Cluster 2	Our global sourcing does analyses and we know quite well how much capacity there is available for us. (C1)	Monitoring suppliers	Visibility	
Not perishable	MTS	Divergent	Cluster 2	For example, you will inform your local management team about the problem, how are we going to solve it, what actions are we planning for, to prevent panic in the plant. But also that everyone is aware of the problem. (E2)	Action plans		
Not perishable	MTS	Divergent	Cluster 2	The suppliers need to have a FMEA (Failure Mode and Effect Analysis), so they need to do risk assessments. (C2)	Monitoring suppliers		
Not perishable	MTS	Divergent	Cluster 2	But when I got a quality issue for that supplier, I decided to take advantage of that to fully go through their process. (C1)	Monitoring suppliers		
Not perishable	MTS	Divergent	Cluster 2	So, this is our approach: trying to monitor early in the supply chain to see an issue before it comes up. (C1)	Monitoring suppliers		
Not perishable	MTS	Divergent	Cluster 2	We have SPC (statistical Process Control) in which there are tools or parameters to see what effect it has on the quality of our product. A reason of bad quality can be settings in a supplier's process, but also the raw materials from the sub-supplier. (C1)	Monitoring suppliers		
Not perishable	MTS	Divergent	Cluster 2	Monitoring them to see their effect on the supplier's product. We do go back in the supply chain like that. From a quality issue, we create awareness at the supplier and then we partner up to see how we can help each other with each other's expertise to eliminate quality issues. (C1)	Monitoring suppliers		
Not perishable	MTS	Divergent	Cluster 2	but then still this location might take care of their own monitoring of KPIs and delivery performance with this specific supplier. (E2)	Monitoring suppliers		
Not perishable	MTS	Divergent	Cluster 2	Imagine that there is a period where delivery performance is bad, then we organize daily calls with our supplier. We then discuss our daily progress. (E1)	Monitoring suppliers		
Not perishable	MTS	Divergent	Cluster 2	Yes. You actually want to have a dashboard with your critical suppliers, with a composed set of KPI's, which you constantly monitor. That can be about inventory, OTIF, deviations, etcetera. (E1)	Monitoring suppliers		
Not perishable	MTS	Divergent	Cluster 2	At that time we quickly established a crisis team and gave the supplier a financial injection so that it could pay its personnel and resume its production. (C1)	Crisis teams	Velocity	
Not perishable	MTS	Divergent	Cluster 2	When there is a crisis, we have a task force team. This means that they had to drop all their work and work completely on solving this crisis. (C1)	Crisis teams		

Appendix 3

	Cluster 1: Discrete		Cluster 2: Mixed			Cluster 3: Process		
	Case A	*Case B*	Case C	Case D	Case E	Case F	Case G	Case H
Flexibility	• Flexible order amounts	• Flexible order amounts	• Agreed with suppliers on 5-10% switch in volume	• Flexible partners for converting end product	• Flexible distribution partners for storage and transport	• Flexible distribution partners for transport	• Flexible distribution partners for transport	• Extra transport possible in urgent situations • In case of a disruption, machine suppliers can deliver faster
	• Parts related to specific end product, not able to switch or postpone	• Parts related to specific end product, not able to switch or postpone	• Fixed production process	• Fixed production process	• Fixed production process	• Fixed production process	• Fixed production process	• Fixed production process • Relatively fixed volumes since companies are connected
Redundancy	• Supplier holds inventory close to factory • High amount of unique supliers	• Supplier holds inventory close to factory • High amount of unique supliers	• Safety stocks • Dual sourcing for critical products	• Safety stocks	• Safety stocks • Back-up suppliers	• Stock based on importance of customer • Dual sourcing for critical products	• Dual sourcing for critical products • High safety stocks	• Building inventory • High safety stocks
	• Low inventory	• Low inventory		• Single sourcing, dependent on 2 raw material suppliers				• Mainly single sourcing, a few main suppliers
Collaboration	• EDI systems, share forcasts • Developing suppliers and resource sharing	• Sharing forecasts • Organized supplier performing programs • Resource sharing	• Provide training on awareness and quality for critical suppliers	• Sharing forecasts and production plan	• Frequent communication with distribution partners on volumes • Sharing forecasts with critical suppliers • Review meetings for improvement of suppliers	• Daily contact with farmers • Collaborative system with distribution partner and farmer • Sharing forecasts with farmers	• Close collaboration, joint development of blends and daily contact with farmers • Sharing forecasts with farmers	• Transparent communication within cluster of companies
			• Not sharing forecasts with suppliers	• No resource sharing		• No system to share forecasts with other partners		• Not sharing forecasts
Agility	• Monitoring suppliers, department for quality • Acting fast on disruptions, often before it is problematic • Scenario's and action plans	• Monitoring suppliers, capacity risk management team • Crisis team • Incentivize suppliers to create an action plan	• Supplier monitoring mainly on quality • Joint contingency plans with suppliers • Crisis teams in case of a disruption	• In case of a disruption, customer allocation priority	• KPI dashboard to monitor critical suppliers • Contingency plan for certain problem category	• Monitoring farmers for quality of raw material	• Monitoring deliver reliability • Monitoring on quality of raw material	• For some scenario's there are action plans, not for disruptions
				• No supplier monitoring • No proactive action plans		• Back-up plans only for transport • In case of a disruption, customer allocation priority	• Simple monitoring in Excel, not automatically in systems • No action plans for disruption	• No supplier monitoring • In case of a disruption, customer allocation priority

Table A2. Overview of resilience practices by case