Process innovation in supply chains –
Towards a method for achieving process-technology fit

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St. Gallen, May 24, 2022

The President:

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Vorwort

Diese Dissertation markiert den erfolgreichen Abschluss meiner Tätigkeit am Institut für Supply Chain Management der Universität St.Gallen (ISCM-HSG) in den Jahren 2018 bis 2021. Während dieser intensiven Zeit durfte ich neben meinem Forschungsvorhaben auch diverse Praxisprojekte in den Bereichen Supply Chain Management, Einkauf, und Digitalisierung verantworten und mit einer Vielzahl interessanter Persönlichkeiten zusammenarbeiten.

Entsprechend bin ich froh über den bestrittenen Weg und blicke auf eine in vielerlei Hinsicht bereichernde Zeit zurück. Doch gab es auch schwierige Momente während des Doktorats, und der Erfolg wäre ohne die Unterstützung diverser Personen nicht möglich gewesen. Ich möchte das Vorwort der Dissertation nutzen, um diesen Personen meinen Dank auszusprechen.

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Besonders an den schwereren Tagen des Doktorats ist ein positives Umfeld unabdingbar. Folglich gilt mein grosser Dank den vielen Kollegen am Institut und darüber hinaus, die für mich die langen Tage, Abende, und Wochenenden im und neben dem Büro zu einer unvergesslichen Zeit gemacht haben. Allen voran danke ich Dr. Raphael Preindl, der mir seit Beginn des Doktorats als Wegbegleiter zur Seite stand und zu einem geschätzten Freund und Ratgeber wurde. Von seiner makellosen Organisationsfähigkeit durfte ich unzählige Male profitieren. Weiter möchte ich mich bei Dr. Dominik Röck und Dr. Mathias Mathauer bedanken, die mir insbesondere zu Beginn des Doktorats mit Rat und Tat zur Seite standen, und so einen guten Start, fachlich wie auch persönlich,

sicherstellten. Darüber hinaus gilt mein Dank Julian Hess, Tim Brandl, Ferdinand Deitermann, Daniel Langner, Calvin Klein, Thiemo Wambsganss, Eric Piolot, Janic Friz, Ludwig Häberle, Leon Zacharias, Philipp Wetzel, und Victor Wildhaber. Ihr habt meinen Lebensabschnitt in St. Gallen massgeblich geprägt und so zum Erfolg der Arbeit beigetragen.

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Forschung über Unternehmen benötigt Kontakt zu Unternehmen. Deshalb danke ich den vielen Praxispartnern für den engen und fruchtbaren Austausch während Projektarbeit, Interviews, Workshops, und informellen Diskussionen. Dieser enge Kontakt lieferte wichtige empirische Daten für die Dissertation und bestärkte meine Motivation für das Themenfeld. Besonders hervorzuheben sind hierbei Axel Butterweck und Prof. Dr. Robert Alard, die mir neben projektspezifischen Diskussionen auch Einblicke in ihren weitreichenden persönlichen Erfahrungsschatz gewährten.

Ich bin unglaublich dankbar für meine Freundin Kari, die mich während des Doktorats begleitete und dabei stets viel Verständnis für mich zeigte. Du hast mich immer bestärkt und ermuntert, aber warst auch kritisch, immer dann, wenn nötig. Du hast den Erfolg der Dissertation erst möglich gemacht. Danke Kari.

Abschliessend möchte ich von Herzen meinen Eltern, Geschwistern, und Grosseltern danken. Danke für eure Unterstützung und den Rückhalt, den ich bei all meinen Vorhaben erfahre. Ohne euch wäre das alles nicht möglich. Euch sei diese Dissertation in tiefer Dankbarkeit gewidmet.

St. Gallen, im Januar 2022 Stefan Selensky

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List of abbreviations

ABV	Attention-based view
AHP	Analytical hierarchy process
AMT	Advanced manufacturing technology
AT	Agency theory
BPM	Business process management
CPS	Cyber-physical systems
CT	Contingency theory
DEA	Data envelopment analysis
DLT	Distributed ledger technology
DSR	Design science research
GPS	Global positioning system
IDT	Innovation diffusion theory
IOIS	Inter-organizational information systems
IPT	Information processing theory
IS	Information systems
IT	Information technology
LSP	Logistics service provider
RFID	Radio-frequency identification
RQ	Research question
SCM	Supply Chain Management
ST	Stakeholder theory
STS	Socio-technical systems
TAM	Technology acceptance model
TTF	Task-technology fit
VUCA	Volatile, uncertain, complex, and ambiguous

Summary

Market environments of organizations' supply chains have become more competitive and dynamic than ever, mainly for two reasons. First, recent disruptions have illustrated supply chains' vulnerability and put the public spotlight on efficient and effective supply chain management. Second, customer expectations are ever-increasing, adding to the fierce competition between supply chains. Thus, organizations must constantly innovate their supply chain processes to stay competitive. Organizations have often focused on product innovation to differentiate themselves from their competitors in the past. However, process companies like Amazon or Walmart outdo their competition today, facilitating radical and disruptive innovation in their supply chain processes. Technological possibilities to enable process innovation seem endless in this regard. However, most organizations struggle to keep up with technological possibilities, and also research has failed to provide insights specifically for inter-organizational processes in this regard.

Consequently, this research aims to explain how organizations can systematically innovate their supply chain processes by deploying technology purposively. It thereby advocates explicitly for a problem-oriented approach towards process innovation. The thesis handles the topic by examining four different aspects: (1) management of technology pre-adoption, (2) analysis of innovation problems, (3) identification of typical problems and solutions, and (4) integration of the individual findings into an overarching, actionable method. The thesis utilizes socio-technical systems theory, task-technology fit theory, and contingency theory as theoretical lenses to investigate these individual issues. The research comprises four different studies deploying qualitative case studies, design science research, systematic literature analysis, expert interviews, and quantitative clustering.

The thesis' results contribute to theory and practice by shedding light on the influencing factors and corresponding design of technology pre-adoption in supply chain processes. Moreover, they allow examining and classifying innovation problems in supply chain processes and reduce the complexity of various technological applications and their deployment. Overall, this dissertation provides organizations with a comprehensive and detailed method to facilitate radical and disruptive process innovation systematically.

Zusammenfassung

Der Wettbewerb zwischen Supply Chains von Unternehmen ist dynamischer denn je. Einerseits haben jüngste Disruptionen die Anfälligkeit moderner Lieferketten verdeutlicht. Andererseits führen steigende Kundenerwartungen und strenge Regulatorien zu erhöhtem Wettbewerb zwischen Supply Chains. Um konkurrenzfähig zu bleiben, müssen Unternehmen ihre Prozesse ständig hinterfragen und erneuern. Heute übertreffen Prozessunternehmen wie Amazon oder Walmart ihre Konkurrenten, indem sie radikale und disruptive Innovationen in ihren Supply Chain-Prozessen einsetzen. Die technologischen Optionen zur Ermöglichung dieser Prozessinnovationen scheinen in dieser Hinsicht endlos. Viele Unternehmen haben jedoch Schwierigkeiten, mit den dynamischen Technologiemärkten Schritt zu halten, und auch die Innovationsforschung hat in dieser Hinsicht noch kaum Erkenntnisse speziell für interorganisationale Prozesse geliefert.

Ziel dieser Dissertation ist daher die Untersuchung, wie Organisationen ihre Supply Chain-Prozesse durch den gezielten Einsatz von Technologie systematisch innovieren. Die Arbeit plädiert dabei explizit für einen problemorientierten Ansatz zur Prozessinnovation und behandelt das Thema durch die Untersuchung von vier verschiedenen Schwerpunkten: (1) Management der Technologieadaption, (2) systematische Analyse von Innovationsproblemen, (3) Identifikation typischer Innovationsprobleme und Lösungen sowie (4) Integration der Einzelerkenntnisse in eine praktisch anwendbare Methode. Die Dissertation verwendet die Theorie soziotechnischer Systeme, die Task-technology fit-Theorie, und die Kontingenztheorie als theoretische Perspektiven, um diese einzelnen Themen zu untersuchen. Die Forschung umfasst vier Studien, in denen qualitative Fallstudien, designwissenschaftliche Forschung, systematische Literaturanalyse, Experteninterviews und quantitative Datenanalyse eingesetzt werden.

Die Ergebnisse der Arbeit leisten somit einen Beitrag zu Theorie und Praxis, indem sie die Einflussfaktoren und die entsprechende Gestaltung der Technologievoreinführung in Supply Chain-Prozesse beleuchten. Darüber hinaus ermöglichen sie die Untersuchung und Klassifizierung von Innovationsproblemen in interorganisationalen Prozessen und reduzieren die Komplexität verschiedener technologischer Anwendungen und deren Einsatzmöglichkeiten. Insgesamt bietet diese Dissertation Unternehmen eine umfassende und gleichzeitig detaillierte Methode, um radikale und disruptive Prozessinnovationen systemisch zu ermöglichen.

1 Introduction

This thesis examines technology-enabled process innovation in supply chains. More precisely, it analyses organizations' approaches towards process innovation and fit between deployed technologies and process characteristics. Chapter 1, therefore, elaborates the relevance of the topic from different perspectives. Section 1.1 takes the managerial perspective, Section 1.2 elaborates the theoretical problem setting, and Section 1.3 formulates the thesis' goals.

1.1 Practical problem setting: barriers of process innovation at the interfaces of organizations

Organizations face enormous pressure to improve their supply chains constantly. Thereby, increasing competition between supply chains is taking the place of competition between single organizations (Marinagi *et al.*, 2014). The causes of this growing pressure are diverse. First, the pressure is customer-driven. Increasing expectations regarding service, individuality, customization, granularization of orders, and delivery concepts amplify competition. Second, new sustainability requirements call for improving supply chain processes (Alicke *et al.*, 2016). Third, the environments of supply chains are more volatile, uncertain, complex, and ambiguous (VUCA) than ever.

To face these challenges, organizations and their supply chains need to improve agility and resilience while maintaining a high level of cost efficiency (Bennett and Lemoine, 2014). Therefore, improving supply chain performance regarding different strategic goals becomes crucial and contributes to the competitive advantage of supply chains, especially from an inter-organizational perspective (Marinagi *et al.*, 2014). The growing pressure to improve performance draws attention to emerging technological developments and their facilitation to innovate supply chain processes. Recent studies have shown high differences in performance between technologically advanced organizations and those that only use lower-level technologies in their supply chain processes (Geissbauer *et al.*, 2020). Both cost and revenue-based benefits from investments in supply chain improvements are more than twice as high for companies with technologically advanced supply chains (Geissbauer *et al.*, 2020).

Amazon provides a famous example of how technological innovations can improve supply chain performance and provide a significant advantage over competitors. Amazon claims to be a *process company* and has a high level of logistics insourcing with many different technologies in use. Against common practice, they introduced a random warehousing system in their inventory operations. The concept itself is not new, but in combination with carefully selected technological applications such as warehousing robots and scanning systems, made this process innovation a great success. It also delivers value to suppliers, customers, and third-party service providers through optimized information flow (Kessler, 2019). For Amazon, this process innovation enabled the reduction of click-to-ship cycles by 75%, increased warehouse inventory capacity by 50%, and promised tens of millions of customers free two-day shipping (Kessler, 2019). It is important to emphasize that Amazon did not aim for incremental improvement by utilizing technology in their traditional processes but radically re-engineered their processes enabled by novel technological capabilities.

Given this successful example and the rapid growth of technology markets, the benefits of technology deployment in supply chain processes seem apparent. Nonetheless, technological advances in supply chain processes today in many organizations do not match the possibilities. Organizations struggle to implement technologies in their processes for five main reasons:

- *Barrier 1:* Identifying, selecting, planning, and implementing technologies consumes high amounts of resources. Even more, because emerging technologies require high levels of know-how, and the hardware itself is expensive (Autry *et al.*, 2010). Thus, effective resource allocation during technology pre-adoption poses a significant problem for organizations (Busse and Wallenburg, 2011).
- *Barrier 2:* High uncertainty regarding the functionality and interoperability between new and existing systems in and beyond the organization poses a significant risk of technology adoption (Winkelhaus and Grosse, 2019b).
- *Barrier 3:* Technology markets are broader and more dynamic than ever before (Geissbauer *et al.*, 2020). This overabundance in options adds to the uncertainty of decision-makers on how to find the best fitting solutions for their specific problems among a great variety of options (Autry *et al.*, 2010).
- *Barrier 4:* Recent technological developments have brought forward different characteristics than traditionally deployed technologies or information systems. Often summarized under *Industry 4.0*, these emerging technologies are highly

interconnected and enable high physical data integration. Although these characteristics make technologies like cyber-physical systems especially relevant for supply chain management (SCM) and logistics, they pose a barrier to adoption as managers have no experience with them (Winkelhaus and Grosse, 2019b).

- *Barrier 5:* Supply chain processes are very complex to manage from a process management perspective. They reach beyond company borders and are characterized by different stakeholders with different interests. Moreover, often different information systems and standards are in use. They simultaneously involve different supply chain flows such as information, material, and financial or legal assets, which must be accounted for in process design (Vom Brocke and Rosemann, 2014).

Given these barriers to technology-enabled innovation in supply chain processes, organizations need support systematically identifying and selecting technologies for their purposes, especially technologies with new characteristics (Closs *et al.*, 1997a; Essakly *et al.*, 2019; Hamzeh and Xu, 2019). However, this problem becomes more complex as identifying and selecting technologies isolated from the environment does not solve the issue effectively. In practice, technologies seldom unleash their full performance impact in a plug-and-play fashion. Research and practice agree that interactions between technology and context need to be understood and considered to leverage technology effectively (Heine *et al.*, 2003). Therefore, it is necessary to identify and select technologies from the vast and dynamic technology markets and carefully consider the supply chain process and its environment.

At the intersection of process innovation and technology adoption, organizations utilize different approaches to innovate their value creation processes. For incremental process innovation, production management has defined successful approaches and philosophies to enable systematic innovation (e.g., lean management, 5S, Toyota Manufacturing System) (Gorecki and Pautsch, 2021). These approaches facilitate incremental process innovation systematically and have a proven practical track record for continuous process improvements. However, their impact on radical or disruptive process innovation is limited.

In the context of radical or disruptive process innovation, systematic approaches are widely missing in practice. It can be argued if it is possible to fully understand and enable radical or disruptive innovation. Other innovation disciplines have shown attempts to do so. For example, Gassmann *et al.* (2016b) have developed a practice-oriented model to facilitate radical business model innovation by analyzing best practices from different approaches and integrating them into an overarching method. However, similar approaches are still missing in the context of process innovation, especially considering inter-organizational supply chain processes. Thus, in practice, organizations are often approaching disruptive or radical innovation in their processes in an unsystematic way, revealing the following shortcomings:

- *A direct translation of processes with a novel technology*: The process is transferred with minor changes to a new technological system. The radical or disruptive potential of the technology is often not leveraged as the process remains similar (Davenport, 1993).
- *Technology-driven replacement of the current technology-process combinations*: Problems and potential solutions are not analyzed systematically. Potentially better solutions are missed, or solutions are determined too early (Haberfellner *et al.*, 2019). Often, individual technologies are identified and selected based on biases or personal experiences rather than systematically, whereby the rationale for this is unknown (Lianguang *et al.*, 2012).
- *Trial and error:* Different solutions are iterated in an agile manner. This approach can consume many resources until the solution fits the requirements. This approach provides solid results for minor tools or apps deployed in the organization but is not suited for large-scale strategic technology decisions (Haberfellner *et al.*, 2019).

To sum up, practice calls for approaches that facilitate systematic analysis of existing processes, derivation of requirements, and matching these requirements with technological capabilities. Thus, a method that matches process and technology characteristics on an abstract level is necessary to leverage the full potential of technology-enabled process innovation in supply chains. This way, the novel approach systematically enables process innovation for radical and disruptive innovations. Figure 1 illustrates common approaches to process innovation (i.e., direct innovation) and compares them to the ideal-typical approach suggested by this thesis.

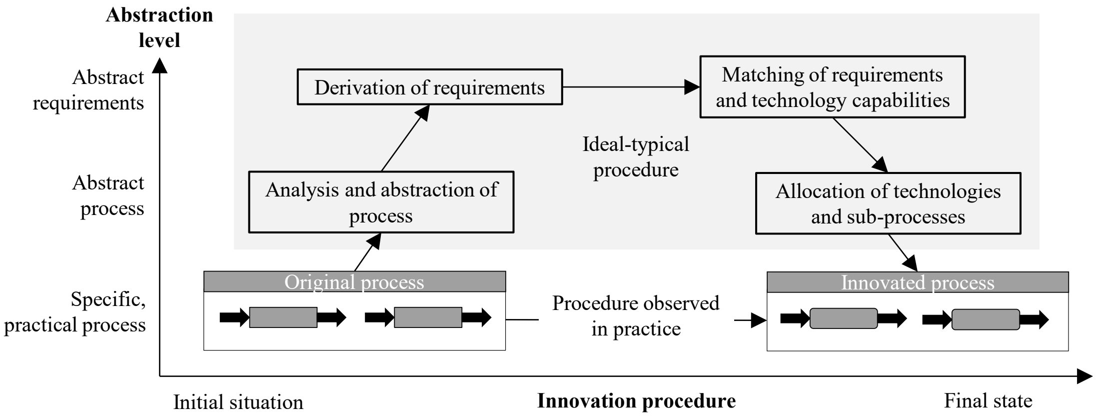

Figure 1: Ideal-typical procedure for radical and disruptive process innovation

1.2 Theoretical problem setting: scholars' lack in theoretical understanding of technology deployment

Identification and selection of technologies become crucial activities in SCM, as deployed technologies must fit the specific purpose and environment. This fit is a measure for resulting benefits during the early stages of technology initiatives, when cost and risk are still comparably low (Selensky and Hofmann, 2020a). Recently, much attention has been given to emerging technologies and their potentially disruptive impact on SCM. In contrast to this excitement, especially in research and consultancy reports, many technologies have failed to live up to these high expectations in practice so far. For example, despite the growing number of initiatives, distributed ledger technology (DLT) has failed to prove its practical impact (Roeck *et al.*, 2020). Even regarding technologies for which a performance impact in supply chains was empirically proven, organizations still need to evaluate skeptically if this impact can be achieved for their specific problem.

Many scholars question the subtle notion that the adoption of technologies itself leads to higher levels of supply chain performance. Instead, certain other aspects need to be considered, such as successful implementation, acceptance of the technology by the users, utilization, and the fit of the technology's capabilities with the requirements, among others (Dishaw and Strong, 1999; Goodhue and Thompson, 1995; Liu *et al.*, 2016; Autry *et al.*, 2010). To anticipate how these necessary conditions can be met by technology deployment in supply chain processes, the concept of fit poses a promising tool in information systems literature (Goodhue and Thompson, 1995; Zigurs and Buckland,

1998) as well as in contingency theory (Van de Ven and Drazin, 1984) and operations management literature (e.g., Drazin and Van de Ven, 1985).

Existing research analyzed technology identification, selection, and fit measures between technology and environment in many research contexts individually. However, regarding the context of identifying and selecting technologies to innovate supply chain processes, empirical and explorative research and the application of the fit perspective are still widely unknown. In general, research on the identification and selection of technologies in SCM, especially considering inter-organizational aspects and taking different technologies from an integrative perspective into account, is still very scarce (Hamzeh and Xu, 2019; Selensky and Hofmann, 2020b). Moreover, existing approaches leave little space for problem-specific adjustment to real-world conditions and provide little insight into the primary constructs of successful technology identification, selection, and technology fit (Bourlakis *et al.*, 2020; Selensky and Hofmann, 2020b).

There is a need for research on how organizations can identify the right technologies from competing options and integrate them to innovate existing processes in SCM. Especially theoretical explanations on how managers approach the potential of a specific technology and justify its benefits are necessary, as recent calls for paper indicate clearly (Bourlakis *et al.*, 2020). Although innovation literature, in general, can suggest clues on these issues, it is essential to note that process innovation is dissimilar to other innovation types such as product innovation in many ways and thus needs to be addressed by specifically dedicated research (Un and Asakawa, 2015; Radnejad and Vredenburg, 2019).

1.3 Thesis goal: enabling systematic innovation and process-technology fit

Based on the managerial and theoretical relevance of the topic outlined in Sections 1.1 and 1.2, this section derives a clear overarching research objective. This thesis examines the fit between technologies and innovation problems in supply chain processes. More specifically, the thesis intends to achieve the following goal:

> Research objective: Developing a method to enable organizations to systematically innovate their inter-organizational supply chain processes by deploying technology and achieving process-technology fit.

Thereby, special consideration is given to the fit between the process, its environment, and the technology deployed to maximize performance outcomes. In sum, the thesis thus aims to elaborate propositions on how to ensure this fit from an organization's perspective while also considering inter-organizational aspects and supply chain partners, to enhance supply chain performance through the deployment of technologies finally.

The overall research goal is approached by pursuing three subordinate research objectives related to each other and the primary goal. More specifically, the subordinate research objectives address both how organizations must manage the innovation procedure and the content of the process innovation. Figure 2 provides an overview of the thesis' research goals based on the managerial and practical implications.

Regarding managing innovation in inter-organizational processes, the thesis aims to analyze the management process of technology identification and selection from an organizational perspective, considering interfaces with network partners. Thus, it aims to identify factors influencing technology management in SCM and propose corresponding responses. From a content-based and technical perspective, the thesis' objectives are twofold. First, it aims to identify typical technology-enabled process innovations and underlying innovation problems in supply chains and to conceptualize them. Researchers and practitioners can use them as guidance to identify relevant characteristics when analyzing technology deployment and process innovation in SCM. Second, the thesis aims to elaborate the concept of fit, as investigated in other research fields, specifically for technology-enabled innovation in supply chain processes. This elaboration results in a generic descriptive model, indicating which technologies fit specific innovation problems.

In sum, the thesis aims to provide a method for systematically analyzing innovation problems in supply chain processes and finding fitting technological solutions to enable radical or disruptive innovation. Therefore, it relates to the procedural and content dimensions. The first dimension guides how the analysis should be conducted and is thus mainly related to the organization's social system. On the other hand, the content dimension describes characteristics of innovation problems, technologies, and fit and thus mainly relates to the organization's technical system. However, the many inter-relationships between these systems are analyzed in detail during the thesis.

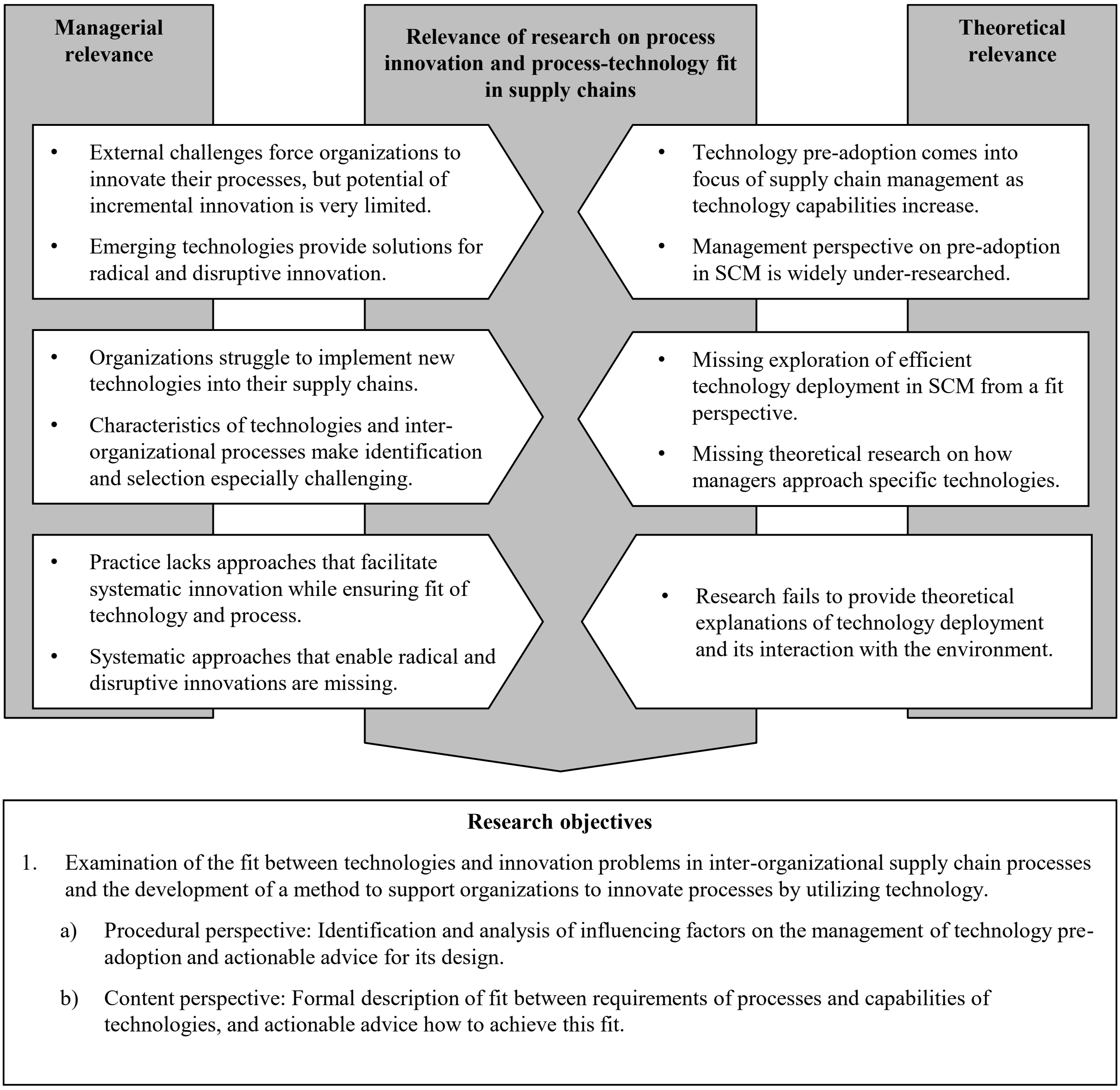

Figure 2: Overview of managerial and theoretical relevance and research objectives

2 Fundamentals

This chapter provides the conceptual basis for research on technology-enabled process innovation in supply chains. First, Section 2.1 defines processes in supply chains and elaborates their specific characteristics. Second, Section 2.2 summarizes and classifies the necessary groundwork from the business process management literature. Third, Section 2.3 characterizes technological innovation in supply chains based on current research. Last, Section 2.4 classifies different types of innovation and places the thesis' understanding of innovation against the literature.

2.1 Characterization of processes in supply chains

Mentzer *et al.* (2001, p. 4) define supply chains as "*a set of three or more entities directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer*." Accordingly, supply chain management (SCM) can be defined as "*the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, to improve the long-term performance of the individual companies and the supply chain as a whole*" (Mentzer *et al.*, 2001, p. 18).

It is essential to note the inter-organizational emphasis of coordination and performance in this definition. Besides the given definition, different perspectives on SCM exist. Mentzer *et al.* (2001) screen extant literature and distinguish three perspectives on SCM: SCM as a management philosophy, SCM as the implementation of management philosophy, and SCM as a set of management processes. As this dissertation focuses on supply chain processes, it adopts the process perspective by specifying the definition given above and viewing SCM as "*the process of managing relationships, information, materials flows across enterprise borders […]*" (Mentzer *et al.*, 2001, p. 10).

Based on this general understanding of SCM, different perspectives on supply chain processes have to be considered. Literature often distinguishes between an organizational and a network level as critical perspectives in SCM. The organizational perspective is characterized by institutionalized management and focusing on a single organization's goals. On the other hand, the network perspective considers the whole supply chain characterized by a lack of formal hierarchy or institutionalized management. Therefore, it must be assumed that all actors follow individual incentives but contribute to the network's goal to maximize performance regarding the end-product (Kopfer *et al.*, 2005; Ojasalo, 2004; Eßig *et al.*, 2013).

The analysis solely at the organizational level does not seem suitable for the goals of this thesis because supply chain flows have become highly inter-organizational, and collaboration with supply chain partners is highly influenced by new technology. Moreover, competition among supply chains pressures companies to collaborate even closer, as elaborated in Section 1.1.

An investigation of technology-enabled process innovation from a neutral perspective on the network-level does not seem purposeful for two reasons. First, a neutral institution to initiate and execute the process of technology pre-adoption does not exist in practice. Thus, findings would hardly be applicable in practice, and access to empirical data would be scarce. Second, technology pre-adoption primarily takes place in a single company considering interfaces to supply chain partners. Network-level investigations become meaningful only when a technology initiative has matured into the adoption or post-adoption phase (e.g., the diffusion of the technology in the network after adoption by an actor).

Because both perspectives do not seem to fit this thesis's goal fully, a supply chain-oriented perspective is defined and utilized. The supply chain-oriented perspective primarily takes the organizational level perspective, especially regarding the management and execution of the technology pre-adoption process. The goals of the initiating company are the main focus of the pre-adoption considerations, but the goals of affected supply chain partners are considered collaboratively. Thus, the supply chain-oriented perspective views the focal organization as striving to maximize the process's overall performance, including its own and partners' performance.

Besides the organizational perspective, the thesis restricts the focus regarding the processes considered. This work focuses on processes that reach beyond the organizational level and involve exchanging materials, information, financial flows, or legal flows with other supply chain partners. Figure 3 illustrates supply chain-oriented processes focused on in this thesis. It can be noted that intra-organizational processes like intra-logistics have a supply chain-oriented character due to the integration of information and financial flows that reach beyond the organizations' boundaries.

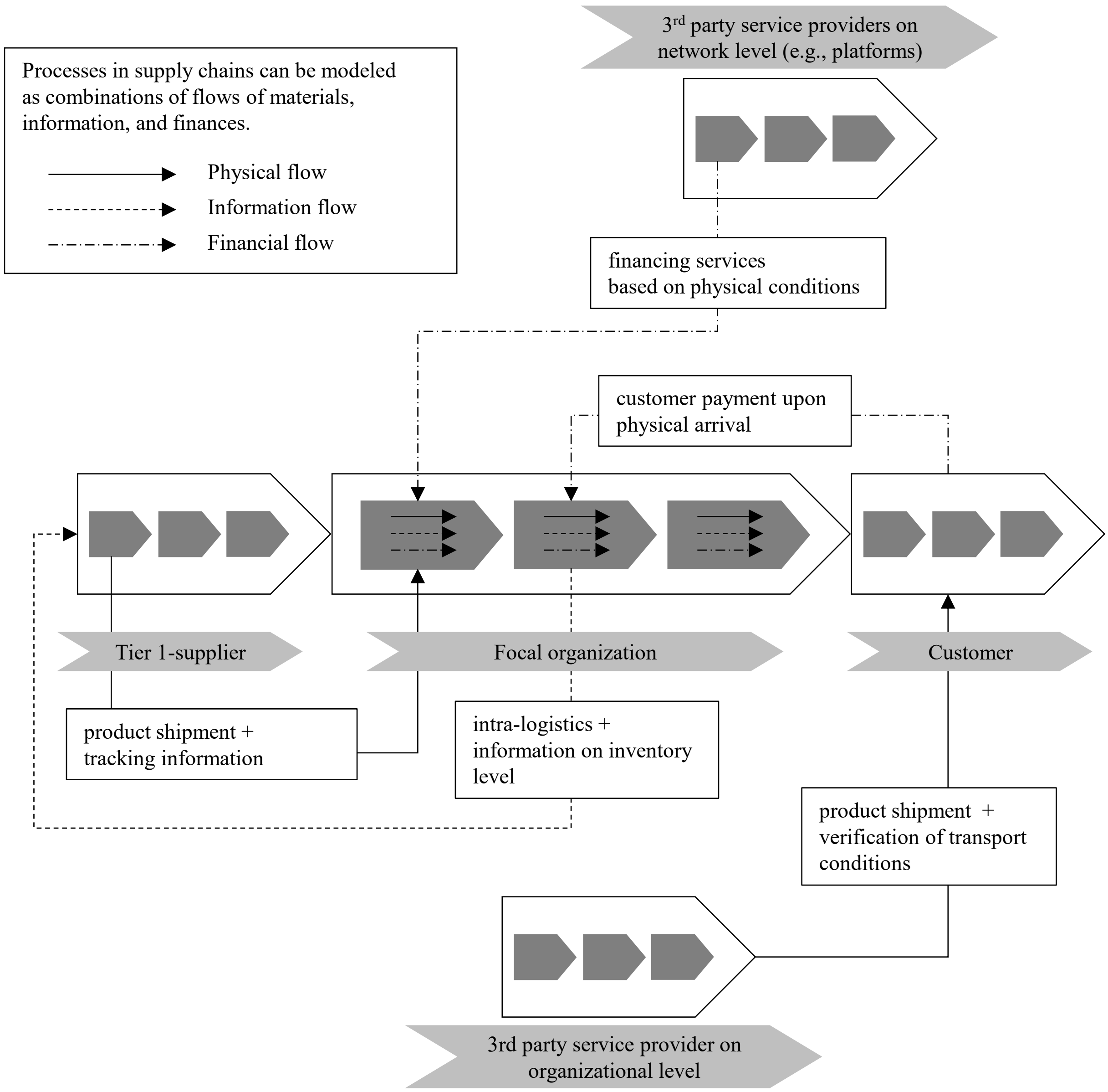

Figure 3: Examples of supply chain-oriented processes in supply chains[1]

2.2 Characterization of business process management and its core components

Business process management (BPM) describes an integrated system for managing business performance by focusing on end-to-end business processes. The research field of business process management originates in two main intellectual antecedents: the quality approach and the process reengineering approach, which have gradually merged into modern business process management (Vom Brocke and Rosemann, 2014).

[1] Supply chain flows regarding legal assets are omitted in Figure 3 for simplicity reasons.

While the quality approach focuses on the execution of processes, the reengineering approach focuses on process design mainly. It states that the process design determines the performance limits of a process, and if the business requirements exceed these limits, the process needs to be re-designed (Deming, 1953; Shewhart and Deming, 1986; Hammer, 1990; Hammer and Champy, 1993). This thesis can utilize the foundations of BPM because they provide a clear conceptualization of three fundamental constructs: processes, the re-design or innovation of processes, and performance. These constructs are addressed differently by the three major traditions of BPM: the management tradition, the quality control tradition, and the information technology (IT) tradition (Vom Brocke and Rosemann, 2014; Shewhart and Deming, 1986).

The thesis utilizes these three traditions by adopting the need for process innovation from the management tradition and by transferring the focus on technology usage of the IT tradition into the industrial, physical asset-related context of the quality control tradition. Thus, it addresses the gap at the intersection of SCM and BPM, where analysis of supply chain-oriented processes with integrated flow objects is still in its infancy.

Research on processes management often uses the terms *process*, *sub-process*, and *activities* to account for different hierarchy levels. Moreover, IS researchers often deploy the term *task* to describe lower-level processes, especially on the individual level. However, the dissertation mainly uses the terms process and sub-process without differentiating further between sub-processes. Nonetheless, the following definitions are adopted for this thesis to streamline different understandings in literature and practice (Weske, 2007; Rummler and Ramias, 2010b; Aguilar-Saven, 2004; Davenport, 1993):

- A *process* consists of a set of activities that are performed in coordination in an organizational and technical environment. These activities jointly realize a business goal. A process may be divided into different *sub-processes*, each following the exact definition of a process.
- The *activities* performed in a process characterize units of work that take different kinds of input and create an output of value.

Regarding *tasks*, definitions appear to conflict with each other slightly. For example, some references provide an individual-centric definition of tasks as *actions carried out by individuals in turning inputs into outputs* (Goodhue and Thompson, 1995). Others use the terms activity and task synonymously (e.g., Weske, 2007; Rummler and Ramias, 2010b) or define tasks as not further refined activities, i.e., the lowest level of subdivision (Chinosi and Trombetta, 2012). As the boundary between activities performed by systems and individuals diminishes, the terms of activity and task are used and interpreted synonymously as lower-level sub-processes in the context of the thesis, both following the value-based definition given above.

2.3 Characterization of technological innovations in supply chains

Autry *et al.* (2010) define supply chain technologies as *the tools and/or techniques that may be implemented in order to effectuate integrated supply chain management within or across organizational boundaries.* In recent years, technological innovation and technology deployment in supply chains have received growing interest. This interest led to an increasing pace of practical discussion and scientific publications on the topic. Therefore, this subsection aims to introduce the major technological trends and draw a picture of their interplay in supply chains. This interplay can be seen as a vision for future supply chains, enabled by emerging technologies allowing inter-connectedness of all actors and things along the supply chain. This vision is often referred to as Industry 4.0 or Supply Chain 4.0; however, this thesis does not limit itself to Industry 4.0 technologies (Geissbauer *et al.*, 2020).

Recent literature identifies seven major technological trends affecting supply chain processes: the internet of things (IoT) and cyber-physical systems (CPS), cloud computing, big data analytics, distributed ledger technology (DLT), additive manufacturing, and robotics. The thesis considers all these main technological trends because they represent great potential for supply chain process innovation and lead to challenges due to their new characteristics, as described in Chapter 1. However, the thesis does not strictly delineate but instead applies a holistic perspective on technology. This work focuses on technologies that facilitate supply chain flows between actors and enable the integration of flow objects (i.e., materials, information, financial and legal assets).

The role of the beforementioned technological trends in supply chains and their potential to facilitate and innovate supply chain-oriented processes and integration of flow objects is elaborated shortly in the following:

- *IoT* envisions an omnipresent internet and comprises the physical world by enabling the communication of physical objects (Mattern and Floerkemeier, 2010).

The term summarizes different technologies such as RFID, Bluetooth, or GPS. IoT facilitates data collection, data transmission, and information sharing in supply chains and thus bridging the gap between physical flows and information flows and between supply chain actors (Azzi *et al.*, 2019; Garrido-Hidalgo *et al.*, 2019a; Meyer *et al.*, 2014). Examples of the impact of IoT in supply chains are possibilities for real-time monitoring of item conditions and information transparency in inter-organizational settings (Bienhaus and Haddud, 2018; Tu, 2018).

- *CPS* describes the integrations of computation with physical processes through embedded computers and networks. They monitor and control the physical processes using loops where physical processes affect computations and vice versa (Winkelhaus and Grosse, 2019b; Lee, 2008). Thus, IoT and CPS build the backbone for integrating physical supply chain flows with information and financial flows.
- *Cloud computing* summarizes technologies that provide ubiquitous, on-demand network access to a common set of configurable IT resources such as servers, applications, or services (Mell and Grance, 2011). It represents a primary condition for many other technological applications, allowing flexible and scalable technology deployment and information sharing in supply chains and reducing transactional costs between actors (Talatappeh and Lakzi, 2020).
- *Big data analytics* summarizes tools and methods that analyze complex data sets to identify patterns and correlations. Due to more extensive data sets (e.g., physical, real-world data collected by CPS and IoT technologies), this poses the opportunity to extract previously inaccessible data and increase business intelligence (Chen *et al.*, 2015; Barenji *et al.*, 2019; Alsghaier *et al.*, 2017). Furthermore, by processing collected data from various sources and organizations, big data analytics provides new ways of monitoring and forecasting in supply chain-oriented processes, also considering various organizations (Handfield *et al.*, 2019; Gunasekaran *et al.*, 2018).
- *DLTs* feature a ledger that is decentral distributed in a network. The well-known example, blockchain technology, works as “a chronological chain of ‘blocks’ where each block contains a record of valid network activity since the last block was added to the chain. Each block could be defined as an encrypted piece of

information.” (Abeyratne and Monfared, 2016). DLT records information received from existing systems in an immutable and traceable way and makes it transparent for authorized supply chain actors (van Hoek, 2019b; Roeck *et al.*, 2020). Thus, it enables supply chain-oriented interaction.

- *Additive manufacturing*, often called 3D printing, represents technologies that incrementally create objects by layering material. This layering stands in contrast to most traditional manufacturing technologies, which usually subtract material using specific tooling (Chan *et al.*, 2018; Delic *et al.*, 2019). Although additive manufacturing represents a production technology and enables many new product-related features, it also facilitates innovations in supply chain processes as it allows for flexibility and automation through data-based, small quantity, and on-demand manufacturing (Chekurov *et al.*, 2018; Sandström, 2016).
- *Robotics* describes machines capable of automatically carrying out complex movements in programmable series. Highly relevant in automation, modern robotics is often part of CPS. Thus, robotic systems enable physical fulfillment and collect and transmit data using sensors and actuators (Morenza-Cinos *et al.*, 2019; Tsolakis *et al.*, 2019).

There are many interactions between these main technological trends, so it is not purposeful to analyze them separately or focus on only one. These interactions and different functionalities along the supply chain yield great potential for integrated, supply chain-oriented process innovation, and thus, the topic must be analyzed from a holistic perspective regarding the technologies. Figure 4 presents an overview of the interplay of the relevant technologies along the supply chain.

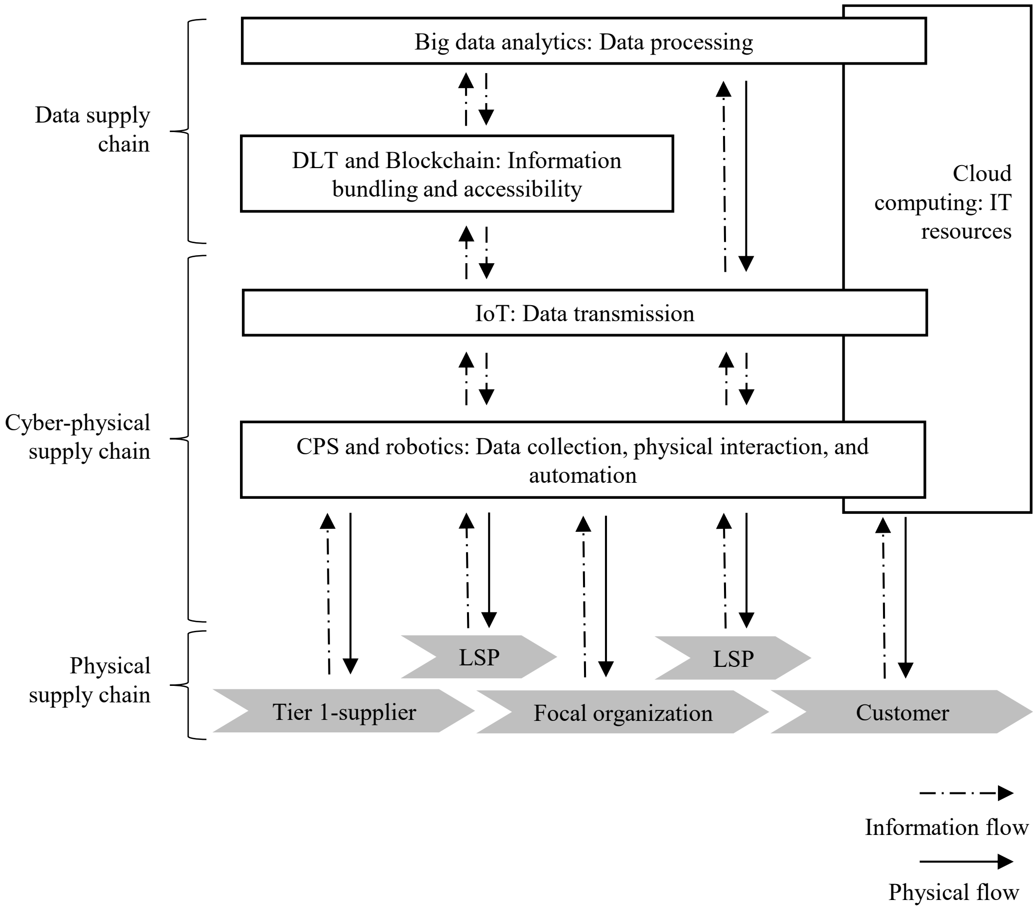

Figure 4: Overview of relevant key technologies and their role in supply chains (adapted from Luu (2020))

2.4 Characterization of innovation types

Innovation management is a broad and multidisciplinary research field. It is the subject of research by sociology, economics, engineering, marketing, and psychology. However, given this broad application and different perspectives, innovation in its core always refers to the creation and adoption of something new (Gopalakrishnan and Damanpour, 1997). In management literature, innovation is often seen as the basis for a competitive economy (Porter and Ketels, 2003).

The most common distinctions of innovation in the literature include the *subject* of innovation, the *source* of innovation, the *degree* of innovation, and the *scope* (Boer and During, 2001; Tidd, 2001). Frequently used subjects of innovation in literature, referring to what is new in an organization, comprise products, services, processes, organizational structures, or people (Knight, 1967; Tidd, 2001). The thesis delimits its focus on process innovations, which can be defined as "*the implementation of new or improved* *techniques, methods, and procedures*" (Wagner and Bode, 2014, p.66). Process innovation states a suitable focus for the thesis because the successful execution of SCM requires the introduction of new processes and the re-engineering of existing processes to facilitate the efficient and effective flows of products, information, and financial assets among supply chain partners (Vijayasarathy, 2010). Moreover, supply chain processes are expected to be highly affected by emerging technology (Hofmann *et al.*, 2019).

Improved techniques, methods, or procedures in process innovation often originate in utilizing the latest technologies in anticipation or response to customer requirements (Scannell *et al.*, 2000). Although other sources of innovation than technology are plausible (e.g., methods or management approaches), the thesis focuses exclusively on technology-enabled innovation in processes (Brem *et al.*, 2016). This limitation seems reasonable because research on new methods or approaches in supply chain processes (e.g., lean management) has a long history already. Therefore, the thesis primarily focuses on technologies that facilitate the integration and exchange of supply chain flows (i.e., physical goods, information, and financial assets) between organizations, including but not limiting itself to Industry 4.0 technologies. An overview of the most significant technological trends was given in Section 2.3.

Academics have discussed and researched the interplay of process innovation and technology deployment intensely in the past. Performing a process unchanged but aided by new technology will not necessarily lead to process innovation and thus also fail to lead to relevant performance improvements. The critical discussion about IT usage in white-collar jobs in the USA in the nineties has shown this issue illustratively. For this reason, the dissertation views technology as an enabler of fundamental process changes and thus innovation, as Davenport proposes in his early seminal work (Davenport, 1993). Hence, a process innovation for this paper consists of a process change (i.e., re-design of the process), which is enabled by technology.

Incremental, radical, and disruptive innovation can be distinguished regarding the degree of innovation. Incremental innovation describes continuous improvement through small changes, while radical innovations offer highly novel approaches. Disruptive innovation describes a re-writing of the existing rules (Tidd, 2001; Dewar and Dutton, 1986). The thesis focuses on radical and disruptive innovation and leaves incremental innovation out of scope. This delimitation seems reasonable as there is a rich literature on continuous improvement already, and also in practice, many successful approaches to enforce these incremental innovations exist (e.g., the lean management philosophy). The potential in this area is thus limited. On the other hand, radical and disruptive innovation is not fully understood yet, and also, in practice, companies struggle with managing and promoting them, as outlined in Section 1.1.

Lastly, the scope of innovation describes to whom the innovation is new. This spectrum can range from innovations that are new to the world to innovations that are only new to a single individual. For this dissertation, innovations to the focal company or the supply chain are inside the scope. This limitation is reasonable, as it fits the supply chain setting and the managerial problems.

To sum up, the thesis considers radical or disruptive innovations in processes where the primary source of innovation or "newness" originates in the deployment of new technology. Moreover, the dissertation focuses on innovations that are new to a specific organization, including the interfaces with the network partners. Figure 5 provides an overview of the different dimensions of innovation and their characteristics in a morphological box. The dissertation focuses on the grey highlighted types of innovation.

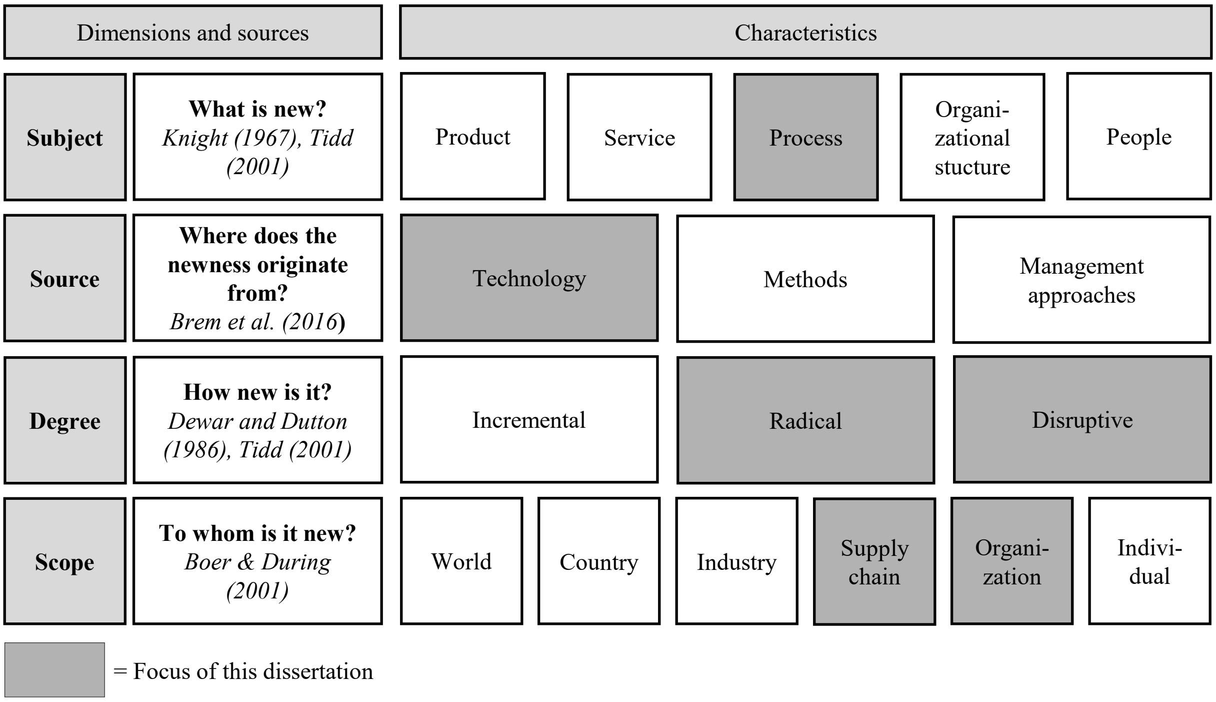

Figure 5: Classification of innovation types and positioning of the thesis

3 Literature review

Chapter 3 analyzes relevant literature on technology-enabled process innovation in supply chains to investigate how organizations can radically and disruptively innovate their processes utilizing a systematical approach. The chapter builds upon the fundamentals from Chapter 2 to conduct a more profound and systematic review of the relevant literature. Each section in this chapter summarizes insights from essential research streams, as indicated in Figure 6. Section 3.1 illustrates the state of research on technology pre-adoption, Section 3.2 on innovation in inter-organizational processes, and Section 3.3 on the theoretical understanding of efficient technology deployment (i.e., fit literature).

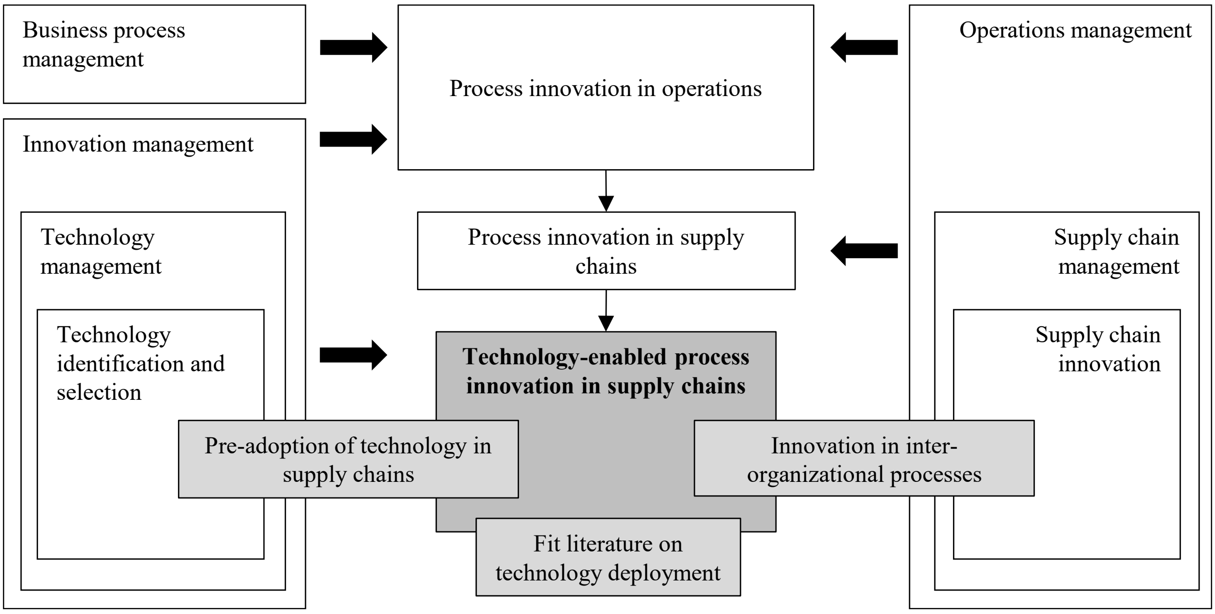

Figure 6: Overview of relevant research streams

3.1 State of research on pre-adoption of technology in supply chains

Zhu *et al.* (2006) distinguish three phases when modeling technology adoption as an ideal-typical process: pre-adoption, adoption, and post-adoption. Similarly, Gregory (1995) proposes a technology management framework from a company's perspective composed of five generic steps: identification of technology, selection, acquisition, exploitation, and protection. Integrating these two widely used frameworks, technology identification and selection can be summarized in the pre-adoption phase. The thesis adopts this understanding of pre-adoption, including identification and selection, and focuses on this phase because the managerial problems identified in Chapter 1 refer to it especially (Scheiner *et al.*, 2015).

Researchers have focused less on technology pre-adoption compared to technology adoption itself in the past[2]. However, two relevant sub-streams can be distinguished: technology identification, which is often referred to as technology foresight, and technology selection. Regarding the first sub-stream, technology foresight examines how companies identify external inputs for innovation to process and evaluate them later (Vishnevskiy *et al.*, 2015). Existing publications focus on the organization of this foresight, success practices, and foresight in network firms (e.g., Rohrbeck *et al.*, 2015).

Regarding the second sub-stream, research on technology selection in operations and SCM examines identifying the most beneficial option from a set of alternative technologies (Singh and Sushil, 1990). A rich body of literature on the topic exists because the critical importance of technology for supply chains' competitiveness becomes increasingly apparent (Hamzeh and Xu, 2019; Armayor *et al.*, 2011b). Although the two sub-streams are often researched separately, this thesis avoids a clear delineation between technology identification and selection. The managerial problems raised in Section 1.1 arise from the difficulty of identifying relevant technologies in complex and dynamic markets and selecting the most beneficial one. Because the two phases are highly intertwined, managerial issues arise during both phases. Therefore, the thesis analyzes them combined with an emphasis on technology selection.

Hamzeh and Xu (2019) recently reviewed the technology pre-adoption literature. They examined selection methods and applications in research from 1990 to 2017. Thereby, they differentiate selection criteria into tangible, intangible, quantitative, and qualitative categories based on the literature. Separating economic, technical, environmental, and social criteria provides another grouping of selection criteria. Methods used during evaluation and selection comprise analytical hierarchy processes (AHP), data envelopment analysis (DEA), fuzzy logic, financial analysis, mathematical programming, and hybrid methods are the main categories in recent research. It is worth noting that these models are applied on a very detailed level regarding technology and applied problems.

Analyzing important publications in the field in more detail, it becomes apparent that most of the publications originate in operations research and predominantly analyze the selection of production technologies (e.g., Naik and Chakravarty, 1992; Almannai *et al.*,

[2] The literature review in Section 3.1 is partly overlapping with Appendix A, which can be consulted for more detailed insights on technology pre-adoption literature.

2008) and advanced manufacturing technologies for producing companies (e.g., Kuei *et al.*, 1994; Thomassen *et al.*, 2014). In addition, there are few relevant papers on the adoption of technologies in supply chains (e.g., Liu *et al.*, 2016; Zhang and Dhaliwal, 2009; Autry *et al.*, 2010), but relevant work in this area refers to either very specific sub-questions or superordinate topics, for example including supply network design (e.g., Elhedhli and Gzara, 2008).

Most of the previous work has a conceptual nature from a methodological perspective. Some papers solely rely on literature for modeling new selection approaches, tools, or frameworks (e.g., Collins and Williams, 2014; Xia *et al.*, 2017; Khatri and Srivastava, 2016; Armayor *et al.*, 2011b; Farooq and O'Brien, 2012). Others illustrate developed selection models or processes by application on a case study (e.g., Essakly *et al.*, 2019; Chuu, 2014; Büyüközkan *et al.*, 2012; Ribeiro *et al.*, 2016). Only a few of the identified publications are empirical. Thomassen *et al.* (2014) propose an approach for decision support to select automation technologies based on the action research methodology. Also, Farooq and O'Brien (2015) facilitate an empirical action research approach to develop a technology selection framework from a supply chain perspective.

One of the few explorative studies on the topic is provided by Hassan *et al.* (2015), analyzing factors affecting selection decisions of auto-identification technology in warehouse management before contributing an own multi-stage selection framework. In addition to their literature review, the authors conduct a Delphi study to investigate key decision-making factors and their importance. Generally speaking, empirical, qualitative, and explorative studies are still scarce at the intersection of technology-pre adoption and SCM.

To sum up, there is notable growth in technology pre-adoption research, especially related to product design and production processes. However, little attention has been paid specifically to technology pre-adoption in SCM or inter-organizational processes (Hamzeh and Xu, 2019). Moreover, existing research on technology pre-adoption lacks methodological variety and examinations from different situational perspectives (e.g., research from an innovation management perspective), as most publications focus on decision-making. Lastly, the identified literature lacks theory utilization and development and is seldom grounded on empirical data.

3.2 State of research on innovation in inter-organizational processes

Innovations in technology impact the performance of supply chain processes regarding efficiency and effectiveness (Bowersox *et al.*, 1999). These performance improvements relate to the revenue-side of organizations by increasing competitive advantage (e.g., by increasing sales) or by reducing the cost and asset utilization, among others (Lancioni *et al.*, 2000; Lancioni *et al.*, 2003; Gunasekaran and Ngai, 2004). Therefore, the relevance and the potential of process innovation in supply chains are widely acknowledged in the literature[3]. However, few studies investigate process innovation in supply chains in-depth and explore its content and the conceptual foundations (Arlbjørn et al., 2011).

Two major research fields can be distinguished dealing with technological opportunities in inter-organizational processes. First, information systems (IS) research studies the topic under the term *inter-organizational information systems (IOIS)*. These can be defined as systems facilitating digital data transmission between separate organizations (Kauremaa and Tanskanen, 2016). Publications in this research stream mainly investigate necessary technological infrastructure for the inter-organizational exchange of information and identify and classify benefits of IOIS (Banerjee and Kumar, 2002; Narayanan *et al.*, 2009).

Moreover, IS research has often discussed technological support of inter-organizational processes under the topic of electronic data interchange (EDI). However, researchers conclude that while traditional business process management (BPM) methods have leveraged impressive benefits on an organizational level (e.g., process efficiency, productivity, continuous improvement, or performance reporting), they hardly apply to inter-organizational processes. Reasons for this limited applicability arise mainly due to the utilization of different systems, standards, or protocols among different organizations (Van der Aalst, 2013). Nonetheless, a research stream trying to leverage traditional BPM methods for inter-organizational processes exists (e.g., Engel *et al.*, 2016). Similarly, Oh *et al.* (2011) identify the need for organizations to expand process management onto the inter-organizational level to stay competitive. However, existing publications only focus on digital, information-based workflows while neglecting material, financial, or legal flows.

[3] The literature review in Section 3.2 is partly overlapping with Appendix B, which can be consulted for more detailed insights on process innovation in literature.

The second research stream studying technology and inter-organizational processes is supply chain integration literature. Publications in this research stream mainly examine the management of partner integration (e.g., Chen *et al.*, 2009), the inter-relationship of integration and performance (e.g., Wong *et al.*, 2011), or antecedents of supply chain integration (e.g., Wong and Boon-itt, 2008).

However, research in this field seldomly provides an integrated view on inter-organizational process design concerning technological capabilities and resulting performance impacts. Existing research either focuses on IT in their analysis or supply chain integration, but the detailed inter-organizational processes that portray supply chain integration are often neglected in extant research. Moreover, extant research at the interface of technology and inter-organizational processes mostly also takes a traditional IS perspective, focusing on information flows mainly. This focus does not seem appropriate today as emerging technologies aim towards a cyber-physical supply chain, integrating information with other supply chain flows. In this context, researchers call for further studies on the processes deployed in effectively used IOIS (e.g., Narayanan *et al.*, 2009).

Besides these two major research streams, more distributed research exists on technology and innovation in supply chains. A great variety of research focuses on explaining and predicting the contributions of supply chain innovation in specific environments or processes. However, current research rarely focuses on theoretical contributions to design and action regarding how to achieve technology-enabled process innovation in supply chains (Wong and Ngai, 2019; Bourlakis *et al.*, 2020). Therefore, researchers call for coherent classifications to enhance conceptual understanding and operationalize supply chain process innovation (Wong and Ngai, 2019; Arlbjørn et al., 2011). Thereby, knowledge during the pre-adoption phase and insights on analyzing existing processes to identify matching technological solutions is still scarce (Wang et al., 2019; Wong and Ngai, 2019).

To sum up, IOIS, BPM, and supply chain integration literature inform research on innovation in inter-organizational processes. However, publications from the IOIS and BPM fields neglect integrated supply chain flows concerning physical, financial, or legal assets. On the other hand, publications from the supply chain integration field lack a clear process orientation. Research lacks theoretical contributions and practical approaches to facilitate inter-organizational process design considering technological capabilities, such as methods or conceptualizations.

3.3 State of research on the theoretical understanding of efficient technology deployment

The concept of fit is widely used in literature to describe the inter-relationships of different constructs that lead to specific outcomes[4]. For example, contingency theory states that the design of an organization must fit with the environment and its sub-systems. However, it is applied to many other contexts and promotes the general notion that there is no single best way to manage a situation (Fiedler, 1964). Another example is organizational information processing theory. It identifies three essential concepts to explain how organizations deal with complex and dynamic environments: information processing needs, information processing capability, and the fit between the two to obtain optimal performance (Premkumar *et al.*, 2005).

Several models explain the interplay of technologies and their surroundings regarding the specific relationship between technology and performance. In their meta-analysis, Heine *et al.* (2003) identified 16 different models investigating the relationship between technology and performance. Results of these models vary widely regarding their level of analysis, which reaches from individuals, groups, and processes to whole organizations. Also, identified models vary in their definition of technology, either analyzing the relationship for a particular technology or a very holistic view on technology, including processes and people. Lastly, models differ regarding their performance measurement, containing subjective and objective measures. Heine *et al.* (2003) find that these inconsistencies in construct definitions make it significantly challenging to compare findings and build upon existing research in this field.

Four models identified explicitly deal with the fit between technology usage and performance, while others express the constructs in moderation or mediating relationships. These four models are the task-technology fit model (Goodhue and Thompson, 1995), independent effects model (Georgantzas and Shapiro, 1993), effects of employee skills on advanced manufacturing technology (AMT) performance model (Pagell *et al.*, 2000),

[4] The literature review in Section 3.3 is partly overlapping with Appendix C, which can be consulted for more detailed insights on technology-fit models in literature.

and process-technology fit on manufacturing performance model (Das and Narasimhan, 2001). For this thesis, the models of Goodhue and Thompson (1995) and Das and Narasimhan (2001) are especially relevant because they explicitly focus on processes and allow ex-ante evaluation of technology deployment in a specific context. They are outlined in more detail in the following as the remainder of this thesis builds upon this knowledge. Das and Narasimhan (2001) investigate the fit between process environment and AMT and the resulting impact on manufacturing performance. They elaborate ideal types of aligned process environments and AMT investments leading to superior performance. However, their findings mainly concern manufacturing processes, differentiating between job shops and assembly lines. Also, their study is particular regarding the technology definition, solely focusing on AMT. Thus, their findings have limited potential for application in a supply chain setting with inter-organizational processes and are unsuitable for different technologies.

In contrast, Goodhue and Thompson (1995) provide a broader perspective on efficient technology deployment by their task-technology fit (TTF) model. Therefore, a literature review on TTF research was conducted to identify seminal publications and applications of the model. TTF describes the relationship between capabilities of information systems (IS), requirements of user tasks, and individual performance of the user. It states that the higher the degree of fit between information system (IS) capabilities and task requirements, the better the system deployment's performance impact (Goodhue and Thompson, 1995). TTF was first published by Goodhue and Thompson (1995) and proved the TTF measure, in conjunction with utilization of the system, improves job performance and effectiveness of individuals significantly. The authors identified eight dimensions of TTF, namely: (1) data quality, (2) locatability of data, (3) authorization to access data, (4) data compatibility (between systems), (5) training and ease of use, (6) production timeliness, (7) systems reliability, and (8) IS relationship with users.

These factors focus on meeting task needs for using data in decision-making, meeting day-to-day operational needs, and responding to changing business needs. Shortly after the first publication on TTF, Zigurs and Buckland (1998) presented an analogous model for groups of individuals. Since then, different model variations have been developed and applied in different contexts, representing variations in the constructs' relationships. For example, soon after TTF's first publication, Dishaw and Strong (1999) proposed integrating the TTF model with the technology acceptance model (TAM), another highly used model in IS literature. Fuller and Dennis (2009) extend the findings on technology and team performance by a time dimension, showing that a better fit regarding technology and task plays a more significant role in short time frames. Over more extended periods, teams innovate and adapt to improve performance even for poorly fitted technologies.

Applications of TTF in research refer to different types of IS and industries. For example, Junglas *et al.* (2008) apply TTF to mobile locatable information systems using a laboratory experiment. Additional to traditional TTF models, they could show that differences between under-, over-, and ideal fit had implications on task performance. Ratna *et al.* (2018) deploy the TTF model to the context of hotel reservation information systems. They examine the effect of task and technology characteristics on the compatibility of technology and task and the utilization of the information system. Fu *et al.* (2019) apply TTF to enterprise social media usage in organizations based on different task environments. However, Huscroft *et al.* (2013) are the only ones among the reviewed papers applying the TTF model to logistics or SCM processes. Their survey-based study examines how the use of fitting information technology can support reverse logistics processes by using processing effectiveness and cost-effectiveness as dependent variables to measure performance.

To sum up, achievements in TTF research can be divided into the extension of the model itself and the embedding in IS literature as well as the application in different practical contexts. The model can improve the selection of technologies by anticipating the performance impacts of possible technology deployment. However, the TTF model or similar models have not been applied to processes beyond the individual level, especially not in a supply chain-oriented context. Thus, the theoretical interplay of innovation problems in supply chain processes and technologies deployed in these problems is still not understood in extant research.

4 Research gaps and research questions

This chapter derives the research gaps this thesis addresses based on the reviewed literature on technology pre-adoption, process innovation in inter-organizational processes, and theoretical research on efficient technology deployment, as outlined in Chapter 3. Each of the research gaps is approached with related research questions. The first research gap poses the overarching research gap of this thesis, while the others provide necessary insights to solve the overarching gap adequately. Each research gap relates to one of the studies conducted in this cumulative thesis and summarizes its literature review shortly[5]. The following research gaps are addressed:

A. Lack of approaches that enable organizations to achieve process innovation and process-technology fit systematically.

B. Lack of research deploying a holistic management perspective on technology pre-adoption and providing adaptable guidelines for organizations.

C. Lack of systematic conceptualization of innovation problems in supply chain processes.

D. Lack of theoretical knowledge regarding the interplay of innovation problems in supply chain processes and characteristics of technologies.

4.1 Research gap A: an approach for organizations to achieve process-technology fit in inter-organizational supply chain processes

The literature reviews on innovation in inter-organizational processes and fit literature on technology deployment (Sections 3.2 and 3.3) revealed the following shortcomings in extant research:

- *Lack of dynamic perspective in technology-fit models*: Existing models view fit as static interrelationships but seldomly explain how to achieve it from a dynamic perspective (Heine *et al.*, 2003).
- *Lack of fit-consideration in process innovation approaches*: Approaches to achieve process innovation in general exist. However, they focus on the

[5] The Appendix provides a more detailed derivation of the research gaps in form of the respective studies.

management of innovation (e.g., people or culture) and leave the content-related fit between innovation and innovation problems out of scope.

- *Lack of specificity in generic models*: Systematic approaches or processes models exist, but they have no special consideration for process innovation or process-technology fit. Approaches like Systems Engineering or agile methods like Scrum and Design Thinking fall under this category for creative problem-solving. However, they do not consider specific content or fields related to the problem, making them too generic for particular problems like technology-enabled process innovation in inter-organizational settings (e.g., Haberfellner *et al.*, 2019).

To sum up, existing research either provides very generic approaches for solving a wide variety of problems, holistic guidelines for managing innovation in organizations, or models theorizing on efficient technology use without providing ways to achieve it. Given these shortcomings in existing literature, the overarching research question of this thesis addresses the design of an approach to fill these gaps:

> *RQ0: How can organizations identify and select technologies to systematically innovate their inter-organizational supply chain processes by achieving processes-technology fit?*

4.2 Research gap B: management perspective on technology pre-adoption

The literature review on the technology pre-adoption (Section 3.1) reveals that little attention has been paid to explorative, empirical, and supply chain-oriented research in the field. More precisely, the following shortcomings stand out:

- *Lack of supply chain-specific pre-adoption research*: Many publications on selecting technologies in operations, especially intra-firm production technologies like automation or auto-identification, exist (Hamzeh and Xu, 2019). These contributions only seldomly take supply chain-oriented aspects like inter-organizational processes that reach beyond company boundaries into account.
- *Lack of empirical, qualitative, and explorative research theorizing on the primary constructs when managing pre-adoption*: The literature on technology pre-

adoption has a strong methodological focus on conceptual research, whereas empirical, qualitative, and explorative research has seldomly been applied. Regarding their contribution, extant literature focuses mainly on developing and designing selection frameworks, decision models, or process approaches. These publications try to find the best solution for a specific problem by following the best-practice paradigm (Sousa and Voss, 2008). However, this paradigm is to be questioned, as conditions of companies are unique and variable, and existing solutions in literature leave little space for adjustment.

- *Lack of comprehensive models and approaches*: Extant studies mainly deal with one particular technology, whereas comprehensive models including different technologies are still scarce. As technology markets have become more dynamic and complex in recent years, practitioners and academics need holistic approaches to deal with constantly changing technologies.
- *Lack of a management perspective on technology pre-adoption*: Regarding their perspective, most publications view technology selection as static and content-based rather than as a complex, human-oriented innovation process. Innovation processes have several properties that make them especially hard to manage. Therefore, the management perspective must be considered in a supply chain-oriented setting where different organizations are involved (Boer and During, 2001).

Because of these shortcomings in existing literature, the related research questions mainly address the management perspective on technology pre-adoption concerning supply chain-specific aspects.

> *$RQ1_a$: What contingency factors influence the identification and selection of technologies from a supply chain-oriented perspective?*

> *$RQ1_b$: How must the process of identification and selection of technologies be designed and managed to improve adoption decisions from a supply chain-oriented perspective?*

4.3 Research gap C: characteristics of innovation problems in supply chain processes

Innovation in supply chains has recently attracted considerable interest from research and practice. Nevertheless, there is still limited knowledge of what constitutes process innovation in supply chains and its distinctive characteristics. The literature review on process innovation in inter-organizational processes (Section 3.2) revealed the following shortcomings:

- *Lack of problem focus:* Existing literature mainly follows the philosophy of technology push, examining the deployment of specific technologies and their impact on supply chains (Bourlakis *et al.*, 2020). However, to successfully identify and select technologies, it is essential to consider problem-pull. Hence, a proper understanding of the underlying problems in supply chain processes is necessary.
- *Lack of classification approaches to drive theoretical contributions:* Existing research provides insights on challenges regarding the adoption of technologies (e.g., Ghadge *et al.*, 2020). However, it rarely provides theoretical contributions regarding process innovation design and implementation. In this context, researchers call for the classification and operationalization of the construct of process innovation in supply chains (Wong and Ngai, 2019; Arlbjørn *et al.*, 2011), for theory-driven approaches to understanding emerging technologies in SCM, and for theories that explain how managers can approach the potential of particular technologies (Bourlakis *et al.*, 2020).
- *Lack of focus on emerging technologies and inter-organizational processes:* Classification approaches related to innovation in supply chains focus on technologies and sub-areas of SCM mainly. However, literature in the field falls short of providing insights focused on and considering the specialties of emerging technologies (e.g., Industry 4.0) and inter-organizational processes simultaneously.

The research question related to these gaps focuses on the problem side of process innovation and its characterization. It aims to identify the specific dimensions that define innovation problems, especially considering inter-organizational aspects and potential technology deployment.

RQ2: *What are the constituting dimensions and characteristics that define innovation problems in supply chain processes?*

4.4 Research gap D: archetypes of technology-enabled process innovation and supply chain-oriented process-technology fit

The literature on efficient technology deployment (Section 3.3) identified the following specific shortcomings in extant literature:

- *Lack of theory-driven approaches towards understanding Industry 4.0*: Existing studies do not theorize on the deployment of emerging technologies such as Industry 4.0-technologies in supply chains. Researchers state the need for theory-driven approaches to understanding emerging technologies in SCM and theories that explain how managers approach the potential of particular technologies (Bourlakis *et al.*, 2020). Generally, literature on fit can be identified to have great potential to address these needs. However, so far, existing models, including the task-technology fit model, have mainly been applied on the individual or group level and in the context of information systems. Therefore, extending existing models onto the process level seems necessary with special consideration of inter-organizational processes with integrated supply chain flows (e.g., information and physical flows).
- *Lack of research considering individual technology-enabled process innovations*: There is a keen interest in emerging technologies and their application in supply chain processes. However, extant research mainly focuses on its broad technological implications (Bourlakis *et al.*, 2020). Thus, there is still a lack of research leveraging the vast number of specific, individual technological applications. Furthermore, attempts to structure technologies and SCM have focused solely on technological or strategic considerations and are not based on empirical data.

The identified research gaps address the structured analysis of individual use-cases of technology deployment and theory-driven approaches towards understanding technology deployment in supply chains. Hence, the related research questions aim to utilize empirical data to simplify the variety of use-cases and draw theoretical insights on their primary constructs.

> *$RQ3_a$: What are representative types of technology-enabled process innovation in practice based on their constituting characteristics?*

> *$RQ3_b$: How can the fit between innovation problems in supply chain processes and technology characteristics be described formally?*

5 Theoretical framing

This chapter defines the theoretical anchoring of the thesis. First, the general scientific perspective on the topic is stated before important guidelines of theory selection are described shortly. Then, resulting from these guidelines, relevant theories are identified and discussed, especially evaluating their specific application within this thesis and possible contributions the thesis can make to the theories. Lastly, the overall theoretical framework is presented.

5.1 Research philosophy

Ontology and epistemology often pose as fundamental components of research philosophy. Ontology describes how a researcher views the *nature of reality* (Easterby-Smith *et al.*, 2021). Epistemology defines how a researcher thinks knowledge can be created (Guba and Lincoln, 1994). Ontological and epistemological stances must be consistent, as they influence the corresponding methodological approach used in the research, including methods and techniques (Saunders *et al.*, 2009).

Business research often defines ontology as the *science of being* (Blaikie and Priest, 2017). It elaborates on individual beliefs of what constitutes a fact. Especially in management literature, it handles whether social reality exists independently from the human interpretation or not, thus if it exists objectively or subjectively (Saunders *et al.*, 2009). Objectivism highlights the structural aspects of management and organizations. Differences in management can be explained as a function of different objective aspects. Subjectivism highlights that social phenomena are created by social actors' perceptions and actions (Saunders *et al.*, 2009). In the context of subjectivism, Remenyi *et al.* (1998) stress the importance of understanding reality in-depth to find a more profound truth behind the phenomenon.

The thesis takes the ontological stance of subjectivism because it is necessary to understand the social interaction of relevant stakeholders of a supply chain process. Although structures in affected organizations play an essential role in process innovation, they are not sufficient to comprehensively analyze the phenomenon of technology-enabled innovation in inter-organizational processes. Therefore, the thesis must take the perceptions and actions of supply chain actors into account to find a more profound truth in different aspects of process innovation, as Remenyi *et al.* (1998) have put it.

Epistemology explains the *nature of knowledge* and different ways to acquire knowledge about social reality. Three main perspectives often differentiated are positivism, interpretivism, and realism (Saunders *et al.*, 2009). Positivism views knowledge generation similar to natural sciences as research on observable social reality. Realism states that objects have an existence independent of the human mind. Finally, Interpretivism emphasizes the need to understand differences between humans as social actors and between researching objects contrary to people (Saunders *et al.*, 2009).

The thesis takes the epistemological stance of interpretivism because understanding human and social actions play an essential role in different aspects of the thesis. First, innovation management is highly influenced by the executing manager and the affected employees. Second, the resulting technological innovation is implemented in a social setting that cannot be neglected.

5.2 Theory selection

As outlined in Chapter 4, this thesis builds on three major research streams: technology pre-adoption, innovation of inter-organizational processes, and fit literature regarding technology and performance. Different patterns in theory usage can be observed for these research streams.

Literature on technology pre-adoption: Interestingly, the identified research on how to conduct technology pre-adoption in organizations, especially technology selection, has little recognizable tradition in utilizing theory. Many of the papers related to selection or decision support do not utilize theory (e.g., Farooq and O'Brien, 2012; Baines, 2004; Hassan *et al.*, 2015). Also, Hamzeh and Xu (2019) do not identify patterns in theory usage in their literature review. However, broader literature on innovation adoption or technology search often deploys attention-based theory to model decisions made by organizations.

Literature on innovation in inter-organizational processes: In contrast, theory usage explaining how specific technological innovations impact supply chain processes are highly diverse. For example, transaction cost theory is often used to explain efficiency enhancements based on emerging technologies (e.g., Roeck *et al.*, 2020). Moreover, the technology acceptance model was often deployed to portray the social aspect of employee acceptance towards novel technologies in supply chain processes (e.g., Brandon-

Jones and Kauppi, 2018). Lastly, socio-technical systems theory has its origin and a long tradition in IS research to explain interactions and interdependencies of the technical systems of an organization with the social systems (e.g., Sony and Naik, 2020).

Fit literature on technology and performance: A rich research field focusing on the theoretical relationship between technology and performance exists in literature, as discussed in Chapter 3. For the context of this thesis, two general models are fundamental and utilized in similar studies. First, the task-technology fit theory originated in the IS field and was widely applied in different settings (e.g., Goodhue and Thompson, 1995; Fuller and Dennis, 2009; Junglas *et al.*, 2008). It was also extended by integrating other technology-related models (e.g., Dishaw and Strong, 1999; Davis, 1989). Lastly, the process-technology fit theory was applied in operations research (Das and Narasimhan, 2001).

With the remarkable variety of theoretical approaches in related research fields on the one hand and the absence of theoretical approaches on the other, it is essential to identify suitable theories and scientific constructs to answer the stated research questions. Stölzle (1999) proposes helpful guidelines for theory selection in SCM and logistics research. He emphasizes the importance of defining specific requirements for the concrete research goal and general criteria that selected theories must fulfill. Based on the literature reviews conducted in Chapter 3, the following specific criteria for theory selection are defined:

- The theory must provide insights into the interplay of technologies and the context they are deployed.
- The theory must aid in structuring technology and its organizational context and provide essential constructs for further examination.
- The theory must provide insights into social and behavioral aspects of managing innovation in and beyond organizations.
- The theory must address the great variety of situations and account for them.

According to Stölzle (1999), the following general criteria are essential to identify suitable theories:

- *Theoretical attractiveness*: A research paradigm and orientation towards critical rationalism are the main aspects of theoretical attractiveness. According to

Stölzle (1999), a research paradigm exists when a theory can solve scientific problems, when it is generalizable, and when it ensures high precision. On the other hand, generating hypotheses and having explanatory power is part of a theories' orientation towards critical rationalism.

- *Design orientation*: Design orientation focuses on content efficiency criteria, design variables, and determinants associated with a theory. In addition, the formal aspects of design orientation relate to the empirical relevance, application potential, and informativeness of a theory.
- *Integrative power*: This criterion is met if a theory can enhance existing theories, structure theoretical constructs, and integrate other theories from the theoretical landscape.
- *Adaptability:* This criterion describes the general applicability of a theory to different research contexts and is inter-related with the criteria mentioned above. For this thesis, the degree of fulfillment regarding the other criteria poses a measure for adaptability.

Based on these requirements, eight theories were analyzed for their applicability. They are described and assessed shortly regarding their potential application in research on technology-enabled innovation in inter-organizational processes. This initial assessment is based on the beforementioned, specific requirements of the theory selection procedure.

- *Socio-technical systems theory (STS):* Socio-technical systems theory views organizations as combinations of technical and social sub-systems. The theory concludes that beneficial outcomes in managing organizations can only result when a fit between these sub-systems is achieved (Heller, 1997). Regarding the thesis, the socio-technical systems theory offers a way of structuring technology-enabled process innovation in supply chains.
- *Stakeholder theory (ST):* Stakeholder theory emphasizes the involvement and influence of various internal and external stakeholders like employees, shareholders, suppliers, customers, and political institutions on a single organization (Mitchell *et al.*, 1997). Thus, the aims and interests of these actors impact decisions made in an organization (Freeman, 2010). Therefore, the theory could help

explain technology adoption in inter-organizational settings from a focal firm perspective and co-adopting supply chain partners.

- *Task-technology fit theory (TTF):* TTF states that the higher the degree of fit between information systems (IS) capabilities and task requirements, the higher the performance impact of the system deployment (Goodhue and Thompson, 1995). The authors identified eight dimensions of TTF: data quality, locatability of data, authorization to access data, data compatibility (between systems), training and ease of use, production timeliness, systems reliability, and IS relationship with users. The factors focus on meeting task needs for using data in decision-making, meeting day-to-day operational needs, and responding to changing business needs. In the context of process-technology fit in inter-organizational processes, the theory can explain how and why the deployment of specific technologies leads to performance benefits in supply chain processes while it does not for other technologies.
- *Innovation diffusion theory (IDT):* This theory contributes to understanding how innovations diffuse through social networks over time (Rogers, 2010). It is often referred to in innovation research in general and supply chain contexts (e.g., Holmqvist and Stefansson, 2006; Wang *et al.*, 2010). Innovation diffusion theory could help explain the different stages of adoption by different stakeholders, as the technology-enabled innovations studied in this thesis often reach beyond two or more organizations.
- *Attention-based view (ABV):* Attention-based view theory models companies as systems of structurally distributed attention. In these systems, the cognition and action of individuals are derived from organizational context and situations decision-makers find themselves in. The theory describes the relationship between company behavior and the attention of decision-makers. It states that companies' behavior results from how they channel and distribute the attention of their decision-makers. Regarding this thesis, the theory can explain social and individual aspects of decision-making during the technology pre-adoption in organizations (Ocasio, 1997; Ocasio and Joseph, 2005).
- *Contingency theory (CT):* Contingency theory holds that optimal organization and leadership are contingent upon various internal and external constraints.

Thus, there is no single best way to manage a situation, as successful approaches under certain circumstances may not prove successful under others (Fiedler, 1964). A contingency-based perspective on the interdependency of context and the pre-adoption approach is still missing in extant research, as illustrated by the literature review and the research gaps. Thus, the theory could prove helpful for the thesis and for answering the research questions in this regard.

- *Agency theory (AT):* Agency theory describes the interaction between a principal that delegates work to an agent (Eisenhardt, 1989a). Problems in this relationship arise from two main reasons: conflicting goals of principal and agent on the one hand and unequal distribution of information towards the agent on the other hand. The theory states efficient contract design as a possible solution for these issues. As process innovation in inter-organizational settings involves different stakeholders with different goals and information, it can be interpreted as an agency problem, and thus the theory might apply to the thesis.
- *Information processing theory (IPT):* The basic assumption of this theory holds that organizations face uncertainties that require them to process information in various ways (i.e., an information processing need) (Galbraith, 1974; Tushman and Nadler, 1978). Organizations can cope with these uncertainties by reducing the implied information processing need or enhancing information processing capabilities. According to information processing theory, both increase performance when a fit between information processing needs and capabilities can be achieved. Premkumar *et al.* (2005) applied the theory to inter-organizational settings to enable analysis beyond organizational boundaries. For this thesis, information processing theory could help operationalize the information processing need of a specific innovation problem, the capabilities of technologies, and their inter-relationship.

Based on this first analysis of potential theories considering the specific requirements of theory selection mentioned above, only the following generally seem applicable in the context of process-technology fit and process innovation in supply chains: innovation diffusion theory, agency theory, attention-based view, contingency theory, task-technology fit theory, socio-technical-systems theory. Therefore, these remaining theories are assessed based on the general criteria in a second step (Stölzle, 1999). The results of the second evaluation step are illustrated in Table 1.

Table 1: Evaluation of theoretical attractiveness, design orientation, and integrative power of relevant theories

Theory	Theoretical attractiveness	Design orientation	Integrative power	Applica-bility
Innovation diffusion theory	**High**: Highly used in innovation management to describe the adoption of innovations in networks (Jeyaraj *et al.*, 2006; Wang *et al.*, 2010)	**Medium**: Provides constructs for technology adoption patterns and time (Rogers, 2010).	**Medium**: Was shown to be integrated with contingency theory (Nooteboom, 1994).	**Medium**
Agency theory	**Medium**: AT is often utilized in operations and supply chain management to analyze inter-organizational innovation or governance (Wallenburg *et al.*, 2019; Wilhelm *et al.*, 2016).	**Medium**: AT provides concrete governance mechanisms to cope with information asymmetries during innovation activities at the interfaces of organizations. Bares potential to be operationalized transparently (Eisenhardt, 1989a).	**High**: AT was proven integrateable with the attention-based view (Bednar, 2012; Ocasio, 1997) and institutional theory (Eisenhardt, 1988).	**Medium**
Attention-based view	**High**: ABV is highly used in innovation management, especially for technology management in the early stages of pre-adoption (i.e., technology search) (Kaplan, 2008; Laursen, 2012).	**High**: ABV explains concrete mechanisms of organizations during technology-related decisions (Ocasio, 1997).	**High**: Was shown to be integrated with agency theory (Bednar, 2012) and contingency theory (Ghobadian *et al.*, 2021).	**High**
Contin-gency theory	**High**: CT is often applied in the operations management context in general (Sousa and Voss, 2008) and technology adoption specifically (Bellingkrodt and Wallenburg, 2013).	**Medium**: Easy to operationalize using various factors but limited explanatory value. Also limited explanatory value in fast-changing technological environments (Donaldson, 2006).	**High**: Was shown be to integrated with the attention-based view (Ghobadian *et al.*, 2021), Information processing theory (Luo and Yu, 2016) and Integration with AT (Miles, 2004).	**High**
Task-technol-ogy fit theory	**High**: Very often applied in IS contexts (e.g., Dishaw and Strong, 1999; Fuller and Dennis, 2009). Seldomly used in the supply chain management context (Huscroft *et al.*, 2013).	**High**: Precise operationalization of technology characteristics that lead to fit. However, the characteristics of the problem side are not fully operationalized (Goodhue and Thompson, 1995).	**High**: Assumptions, level, and unit of analysis commensurable with the socio-technical systems model (i.e., STS providing a more holistic view by adding the social system).	**High**
Socio-technical systems theory	**High**: Very frequently applied in IS contexts to explain how IS should be successfully implemented but seldomly used SCM contexts (e.g., Sony and Naik, 2020; Siawsh *et al.*, 2021)	**High**: Enables explaining different elements and their interplay of technologies in their Surrounding (Bostrom and Heinen, 1977).	**High**: Assumptions, level, and unit of analysis commensurable with the task-technology fit model (i.e., TTF providing a more detailed look into the technical system).	**High**

Based on the theory assessment shown in Table 1, the thesis utilizes task-technology fit theory, contingency theory, and socio-technical systems theory as theoretical lenses. The following sections provide a deeper understanding of the selected theories and their utilization and assignment to the research questions of the thesis. Finally, the theory section concludes with an overall summary and integration of all theoretical lenses in a framework.

5.3 Outline of task-technology fit theory

TTF was first developed and demonstrated by Goodhue and Thompson (1995). They proved that the TTF measure, in conjunction with utilization of the technology, improves job performance and effectiveness of individuals significantly. Later, the theory was expanded by Zigurs and Buckland (1998) onto group level. Since then, TTF has been applied in several variations and fields, especially in information systems research. However, only Huscroft *et al.* (2013) apply the theory to SCM or logistics until now.

The TTF framework comprises five main elements: task characteristics, technology characteristics, task-technology fit, performance impact, and utilization. The theory sets these constructs into relation and has proven that the higher the degree of fit between task and technology characteristics, the higher the performance impact for individuals and groups (Goodhue and Thompson, 1995). Goodhue and Thompson (1995) identified eight dimensions of TTF: data quality, locatability of data, authorization to access data, data compatibility (between systems), training and ease of use, production timeliness, systems reliability, and IS relationship with users. The factors focus on meeting task needs for using data in decision-making, meeting day-to-day operational needs, and responding to changing business needs.

TTF plays an essential role in this dissertation. It aids substantially in describing and understanding the relationship between innovation problems in supply chain processes and technology deployment so that researchers can better understand different performance impacts. Based on the primary TTF constructs and their relationship, the overarching research framework of the thesis is developed, and particular studies of the thesis analyze individual elements of the TTF model in detail. Specifically, study B conducts an in-depth analysis of the problem-side of the model and investigates innovation problems in supply chain processes. Study C utilizes an adapted TTF model to explain the interplay of specific archetypes of innovation problems with technological solutions.

The model so far only focuses on individuals and groups supported by information systems as technologies. This limitation calls for a transfer of TTF beyond the individual level onto the process level and application to emerging technologies in supply chain settings. The latter mainly refers to integrated supply chain flows, including information, physical, financial, or legal assets. A theoretical contribution of the thesis thus aims at the expansion of TTF for supply chain-specific problems.

5.4 Outline of contingency theory

Fiedler (1964) introduced CT in a behavioral context before the theory was applied to many other disciplines, such as logistics networks (e.g., Wollenburg *et al.*, 2018) and purchasing (e.g., D'Antone and Santos, 2016; Björklund, 2011). The critical assumption of CT is that organizational structures must consider surrounding conditions, often referred to as situational or contingency factors. Situational factors can be internal or external. The latter are usually hard to influence by the organization as they are outside its boundaries (Mintzberg, 1979). Thus, Mintzberg introduces design variables that are in managerial control for being changed by decision-makers to cope with these surrounding conditions.

Moreover, the theory states that for organizations to be effective, the design of an organization or its sub-systems must fit with the environment it operates in, and the fit between the sub-systems must be ensured. Thus, the management style under given circumstances must take the given tasks and the nature of the work into account (Weill and Olson, 1989). CT states that there is no single best way to manage a situation or organization (Zelt *et al.*, 2018). A fundamental problem in CT research is measuring and operationalizing situational parameters (Otley, 1992). Also, the theory is often criticized due to its lack of explanatory power. Nonetheless, it can provide structure for a wide variety of problems.

Regarding this thesis, CT can provide a novel perspective on research gap B regarding the management of technology pre-adoption in process innovation that the literature identified necessary. A high proportion of operations and SCM research on pre-adoption of technologies follows the best-practice paradigm, searching for the silver bullet on identifying and selecting technologies. However, there are many variations in individual circumstances and potential technologies. Thus, questioning this paradigm and analyzing the interplay of pre-adoption practices and specific surroundings seems necessary. In this context, CT systemizes the relationship between the characteristics of the innovation problem and how the technology pre-adoption phase must be managed accordingly. More specifically, the framework is used to identify and classify internal and external contingency variables of technology pre-adoption and corresponding response variables (i.e., activities to be performed under specific circumstances).

5.5 Outline of socio-technical systems theory

STS aims at understanding and designing the interplay of social and technical subsystems in the context of technology and originated in the seminal work of Bostrom and Heinen (1977). The theory states four core elements to consider when researching technologies and their environments: structures and people as the social sub-system and technology and tasks as the technical sub-system. These elements have inter-dependencies against each other and are considered a predictor of adoption success.

The theory proposes a design process for achieving the inter-dependent optimization of the sub-systems and states that organizations must explicitly recognize technical and social sub-systems' interactions to achieve performance enhancement. Concludingly, organizational re-design must consider these inter-dependencies and ensure that both sub-systems are in harmony (Bostrom and Heinen, 1977). Therefore, different design principles and guidelines exist to develop successful socio-technical systems and enable successful technology adoption.

Several parallels can be drawn to the context of inter-organizational process innovation and technology deployment. First, process innovations can be interpreted as socio-technical systems, similar to whole organizations. Depending on the scope of the analyzed process, the scope of these systems varies. Hence, process innovations in supply chains can be decomposed into a technical sub-system (i.e., the technologies deployed to fulfill specific processes) and a social sub-system (i.e., the structures and the people involved in the process) (Bostrom and Heinen, 1977). The thesis deploys STS for the overall structure, identification, and analysis of relevant elements. The understanding of the technical sub-system's elements is integrated with the explanations provided by TTF, as the main assumptions of the two theories are not conflicting with each other. Structures and people provide complementary theoretical framing in this context.

5.6 Overall theoretical framework

This dissertation pursues an eclectic approach because distinct theories are necessary to answer the stated research questions. The eclectic approach allows the utilization of different theoretical lenses, whereby each can describe, explain, or compose different phenomena. However, it also aims to show interconnections between different theories and thus draws a holistic picture of the phenomenon. Thereby, it is vital to ensure commensurability between the individual theories. During the evaluation of the integrative power of the selected theories in Table 1 and the comparison of the theories' general assumptions, no conflicts were identified. Thus, commensurability for the purpose of this thesis is given (Friedli, 2005).

Figure 7 illustrates the overarching theoretical framework of this dissertation. It integrates all relevant constructs and perspectives to analyze the phenomenon of technology-enabled process innovation in supply chains considering process-technology fit. The framework is explained shortly by its three main perspectives: organizational perspectives, procedural and content-based perspectives, and theoretical perspectives. First, the framework consists of three organizational perspectives: organizational perspective, network perspective, and supply chain-oriented perspective. As elaborated in Section 2.1, the thesis takes the supply chain-oriented perspective throughout all research phases. Thus, it analyzes technology-enabled process innovation from a single organization's perspective with collaborative consideration of all relevant interfaces with supply chain partners (i.e., suppliers, customers, service providers). However, the organizational and network perspectives need to be located in the framework as the supply chain-oriented innovation problem is derived from these two perspectives' combined needs and goals.

Second, the framework can be divided into procedural and content perspectives. The procedural perspective covers *how* organizations reach process innovation in supply chains, resulting in beneficial performance outcomes. Therefore, it comprises the management of the technology pre-adoption procedure under consideration of the innovation problem and its context. On the other hand, the content perspective describes *what* technology-enabled process innovation in supply chains comprises. It can be divided into the problem space and the solution space. The problem space describes the supply chain-oriented innovation problem and its context with all relevant characteristics for technology pre-adoption. The solution space comprises possible solutions to the innovation problem (i.e., available technologies and their relevant characteristics). In line with TTF, the fit construct links problem space and solution space and results in a performance impact on the supply chain.

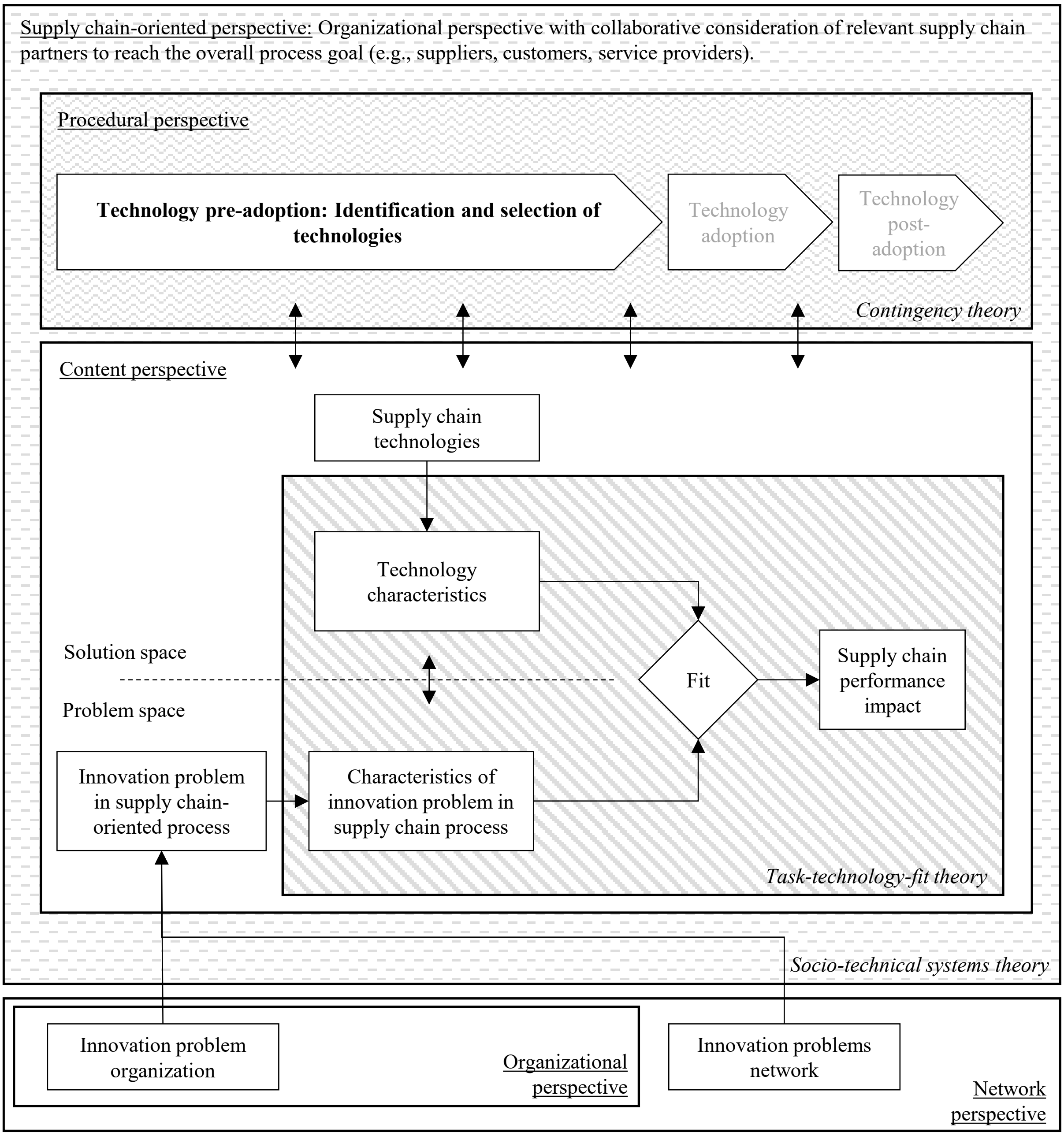

Figure 7: Overview over the theoretical framework on technology-enabled process innovation in supply chains

Third, the theoretical lenses introduced in the previous section are assigned to segments of the framework. Socio-technical systems theory is used as a structural guideline for all the constructs, while contingency theory structures the inter-dependence between procedural and content perspectives. Finally, characteristics of technology and innovation problem, fit, performance impact, and their causal relationship are explained utilizing TTF.

6 Studies on process innovation in supply chains

Chapter 6 provides an overview of the applied research methodology and the individual results of the thesis' studies. Section 6.1 relates the individual studies to each other, considering their methodological approach. Finally, sections 0, 6.3, 6.4, and **Error! Reference source not found.** summarize the studies' research design, findings, and essential contributions.

6.1 Research overview and methodology

The thesis revolves around its central unit of analysis: technology-enabled process innovation from a supply chain-oriented perspective, which is investigated from a procedural and a content perspective. The unit of observation differs between the studies, depending on the individual focus. Study A defines the unit of observation as *management activities in an organization and its context during technology identification and selection*. Studies B and C observe *characteristics of technology-enabled process innovations in supply chains*. The overarching research phase uses both of the above mentioned as the unit of observation.

Figure 8 illustrates the inter-relationships of the thesis' studies and their positioning in the theoretical framework. Study A focuses on the procedure of technology pre-adoption (i.e., how companies can improve adoption decisions in a supply chain-oriented setting to achieve process innovation). Study B focuses on the content perspective, describing and systemizing relevant characteristics of technology-enabled process innovation. Study C builds upon the results of study B and investigates the fit construct between technologies and supply chain processes in detail, determining how and why particular technologies result in performance benefits. Finally, the overarching research phase integrates the findings of the other studies to develop a practical method that enables organizations to innovate their processes systematically by achieving process-technology fit.

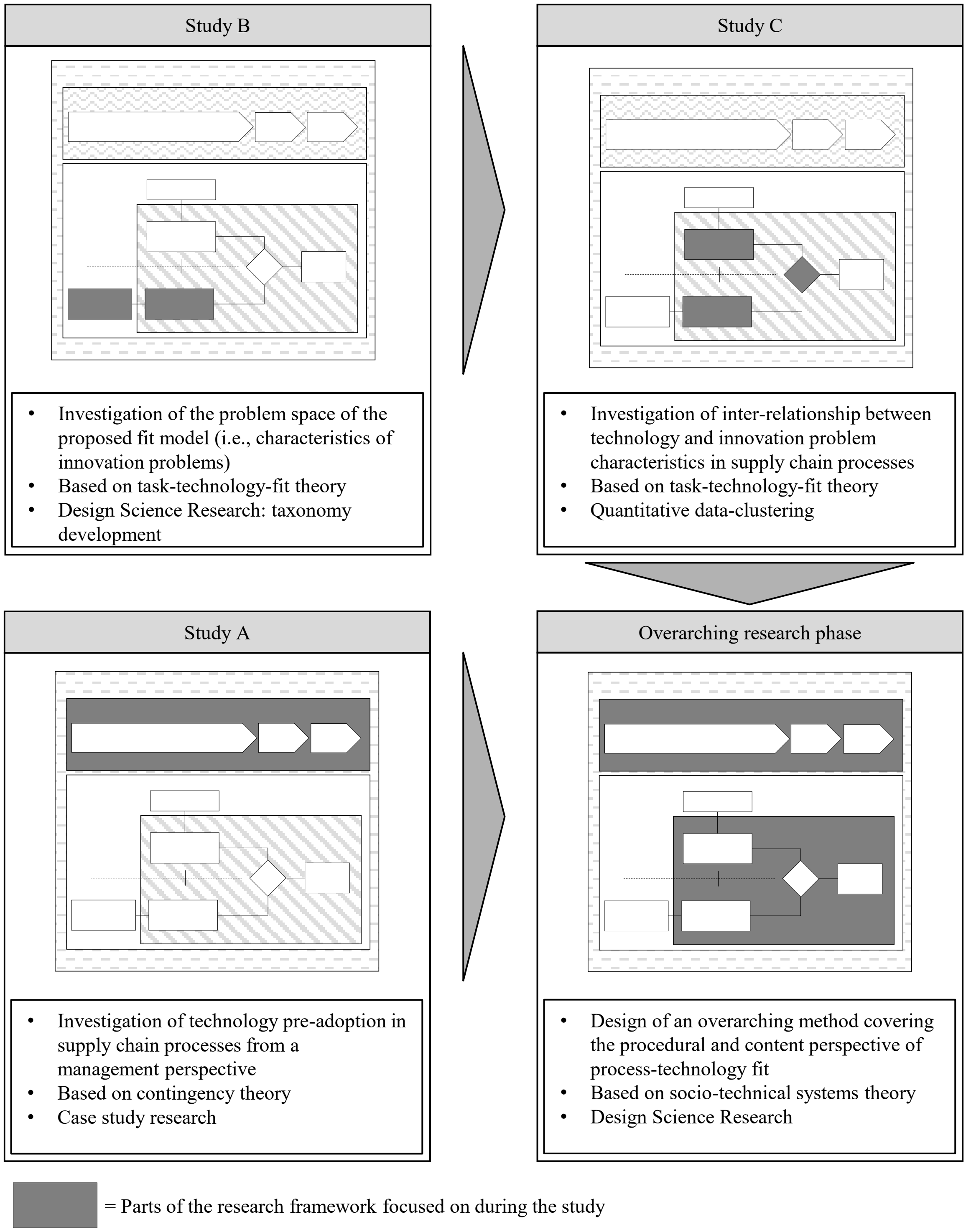

Figure 8: Overview and inter-relationships of the thesis' studies

This thesis's overarching research question and goal are to enable organizations to innovate their inter-organizational supply chain processes by ensuring a fit between the process and deployed technologies. A detailed study was conducted for each research question to contribute to this goal. It is worth mentioning the inter-relationships of these studies. Study A and B lay the groundwork for each perspective and are independent of the other studies of this thesis. Study C builds upon the results of study B, as the collected data points on process innovations are adopted from study B. The overarching research phase utilizes and integrates the findings of studies A, B, and C and is thus strongly dependent on the prior results. Studies A, B, and C have been presented as full papers at international conferences, and studies A and B have been submitted to international journals in the SCM field. However, as the overarching research depends on the prior results, it was not published as a standalone paper besides this thesis[6].

In each study, methods were selected to answer the research questions adequately based on their characteristics. Existing publications on technology-enabled process innovation in supply chains deploy diverse methods, as shown in Chapter 3. However, several methodological shortcomings could be identified. On the one hand, research on technology pre-adoption in operations is mainly conceptual and design-driven. This observation calls for an empirical and explorative analysis of the phenomenon. On the other hand, research on technological innovations in supply chains provides empirical insights on individual technologies but leaves conceptual and holistic approaches missing. This gap in literature calls for design-driven research to structure the phenomenon and the field.

Thus, this thesis applies explorative and conceptual research methods throughout different studies to draw a complete picture of technology-enabled process innovation in supply chains. The thesis moreover relies on qualitative and quantitative research methods and empirically-based data. It is essential to rely on empirically-based data because high expectations in emerging technologies risk unrealistic concepts and ideas being analyzed instead of real-world phenomena. A qualitative approach is pursued because the research questions require an in-depth analysis of the individual concepts. Limitations of qualitative research, especially on the generalizability of the results, are mitigated through rigorous methodology deployment and the combination of different data sources. Lastly, quantitative research methods are utilized selectively to answer the research questions and enhance the generalizability of the findings.

[6] The research approach of the overarching results is deepened in Section 7.1 and the results are outlined in detail in Sections 7.2 and 7.3.

Table 2 provides an overview of the conducted studies, including the vital information regarding their research design. The subsequent sections outline the research design, the findings, and the contributions of each study.

Table 2: Overview of the conducted research on technology-enabled process innovation in supply chains and process-technology fit

	Study A	**Study B**	**Study C**	**Overarching research phase**
Title	Towards a contingency theoretic perspective on technology pre-adoption in supply chain management	The Anatomy of Innovation Problems – Towards a Taxonomy for Supply Chain Processes	Towards a process-technology fit in supply chain management – a theory-driven approach to understanding Industry 4.0	Designing a method to enable organizations to achieve process-technology fit
Objective	Identifying and structuring influencing factors of managing technology pre-adoption in SCM and potential responses of decision-makers	Understanding and conceptualizing the underlying innovation problems in supply chain processes	Theorizing on the interplay of types of innovation problems and technology deployment in supply chain processes	Integrating the findings of studies A, B, and C into an actionable, useful method for practice
Related research questions	$RQ1_a$: What contingency factors influence the identification and selection of technologies in supply chains? $RQ1_b$: How must the process of identification and selection of technologies be designed and managed to improve adoption decisions in supply chains?	RQ2: What are the constituting dimensions and characteristics that define innovation problems in supply chain processes?	$RQ3_a$: What are representative types of technology-enabled process innovation in practice based on their constituting characteristics? $RQ3_b$: How can the fit between innovation problems in supply chain processes and technology characteristics be described formally?	RQ0: How can organizations systematically identify and select technologies to innovate their inter-organizational supply chain processes?
Methodology	• Case study approach; in-depth polar cases of technology pre-adoption in various industries • Second-level coding following Gioia *et al.* (2013)	• Taxonomy development following Nickerson *et al.* (2013) • Systematic literature review • Expert interviews for evaluation	• Quantitative clustering of 79 secondary data real-world use cases of successful technology deployment using Python 3	• Design Science Research following Hevner (2007) • Design informed by literature and results of studies A, B, and C
Applied theories	• Contingency theory	• Task-technology fit theory	• Task-technology fit theory	• Socio-technical systems theory

6.2 Study A: a contingency theoretic perspective on technology pre-adoption in supply chain management

This section provides insights into the in-depth study on the management of technology pre-adoption in supply chains from a contingency-theoretic perspective, as conducted in study A. In the following, relevant contributions to theory and practice, but especially for this thesis' overall goal, are outlined[7].

Research design of study A

Organizations and supply chains face a dilemma between the pressure to implement novel technologies into their processes and limited resources. As a result, organizations' technology identification and selection activities become crucial success factors in operating supply chains. Research on this topic has a rich history, especially in operations and production management. However, much of this research mainly focuses on adoption in manufacturing settings, leaving inter-organizational problems and pre-adoption activities out of focus. Also, extant research lacks an in-depth understanding of the involved constructs of technology pre-adoption and their interactions with different problem settings. Thus, research is still missing a supply chain-specific contingency perspective on the topic.

In contrast to existing research, study A is among the first to view technology selection in supply chains as a management process from a contingency perspective. Thus, it assumes that pre-adoption procedures in organizations must fit the surrounding circumstances to be effective and efficient. The study explores supply chain-specific influencing factors and responses in management activities during technology pre-adoption to enable this fit. It thereby follows a qualitative case study approach. Cases analyzed stem from five interview-based case studies of technology projects. The cases were selected based on four criteria to ensure variety, inter-organizational and supply chain-relevant settings, and technological innovativeness. The data was analyzed using a rigorous coding procedure following Gioia *et al.* (2013).

Findings and contributions of study A

Study A identified and systemized two primary constructs: (1) exogenous contingency variables that influence the management of technology pre-adoption in supply chains and (2) internal response variables that enable accounting for those influences in organizations. These findings provide answers for $RQ1_a$ and $RQ1_b$. The identified contingency variables can be divided into three subgroups on the highest dimension: (1) firm-specific factors, (2) network-specific factors, and (3) environmental factors. The

[7] Section 6.2 largely draws on extracts from the corresponding full paper in Appendix A.

according lower-level dimensions stemming from the cases are illustrated in the coding trees in Figure 9, Figure 10, and Figure 11.

Firm-specific, endogenous factors are often an essential component of contingency models (Kajüter and Kulmala, 2005). In the study, a subset of firm-specific influencing contingency factors was found to be very ubiquitous. This subset consists of criticality, project trigger, employees, and complexity.

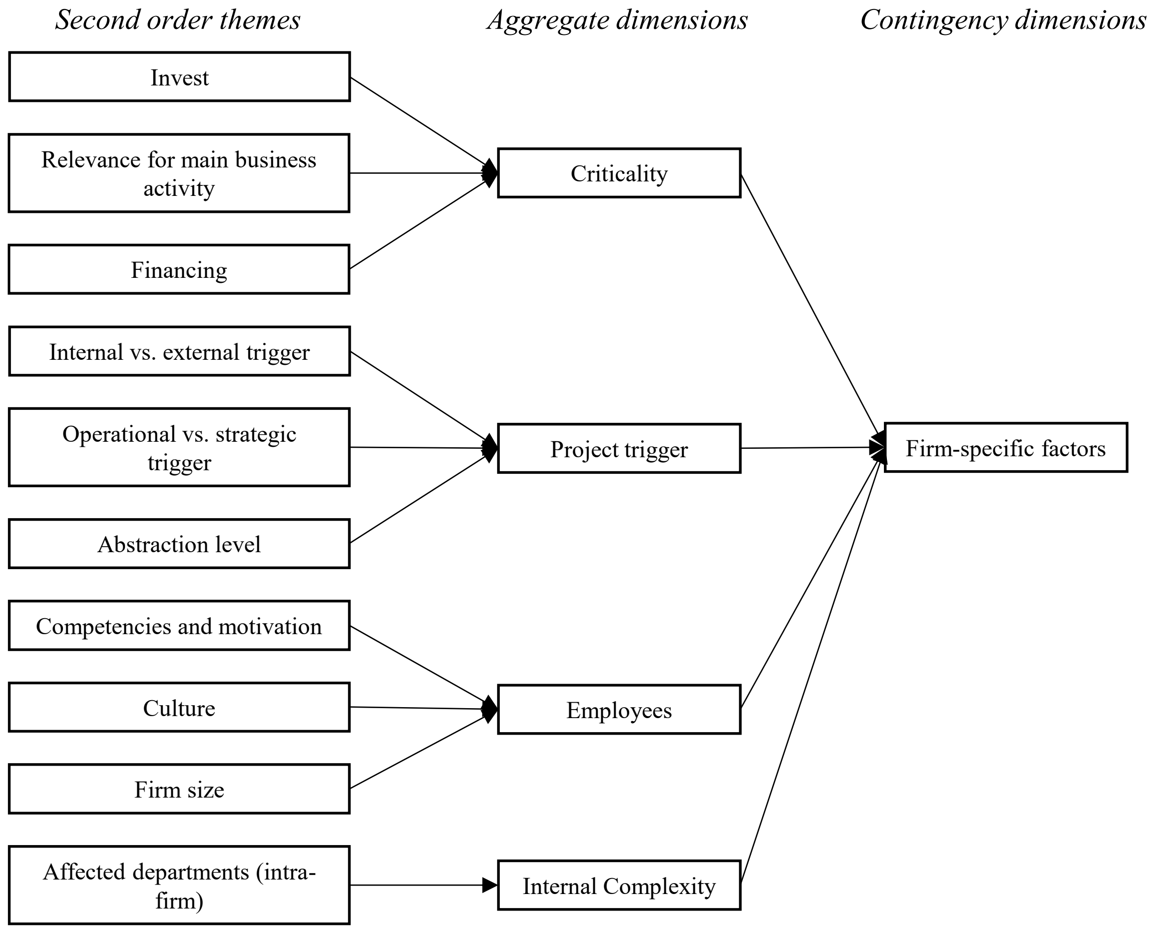

Figure 9: Firm-specific influencing variables on the management of technology pre-adoption in supply chains[8]

Especially in SCM, network-specific contingency factors account for specific situations in supplier-buyer-relationships, such as differences in size and trust among network partners (Kajüter and Kulmala, 2005). The data analysis revealed the crucial role of network-specific factors also in the context of technology pre-adoption. Network-specific variables can be distinguished between external complexity and a strategic

[8] Figure 9 is extracted from study A.

dimension. Complexity refers to the amount and type of interaction with external departments in the network. Strategic aspects primarily cover the presence and types of long-term cooperation. The cases showed these two dimensions to have an exceptionally high impact on technology pre-adoption in organizations.

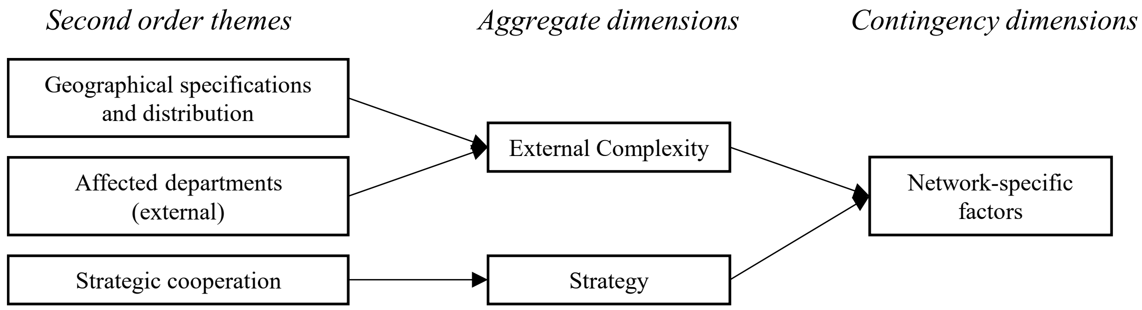

Figure 10: Network-specific influencing variables on the management of technology pre-adoption in supply chains[9]

Lastly, the study discovered that pre-adoption approaches and their success vary depending on external environmental factors. More specifically, characteristics of the technology market and industry regulations play a crucial role in influencing technology pre-adoption.

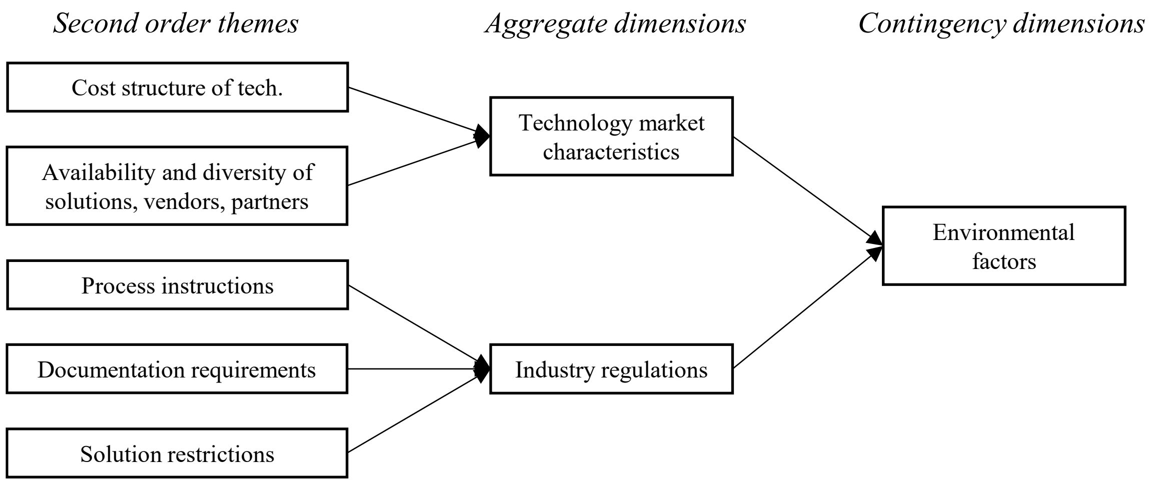

Figure 11: Environmental influencing variables on the management of technology pre-adoption in supply chains[10]

[9] Figure 10 is extracted from study A.
[10] Figure 11 is extracted from study A.

Response variables were inspected during the study besides the contingency variables, which an organization cannot influence. Results showed they could be divided into two sub-groups: (1) pre-adoption process and (2) pre-adoption organization. Response variables in the process sub-group comprise all activities performed, including tools or methods. Response variables part of the organization sub-group cover how the pre-adoption is set up organizationally and include staffing, budget, and the overall approach. An overview of possible processual and organizational responses is given in Figure 12.

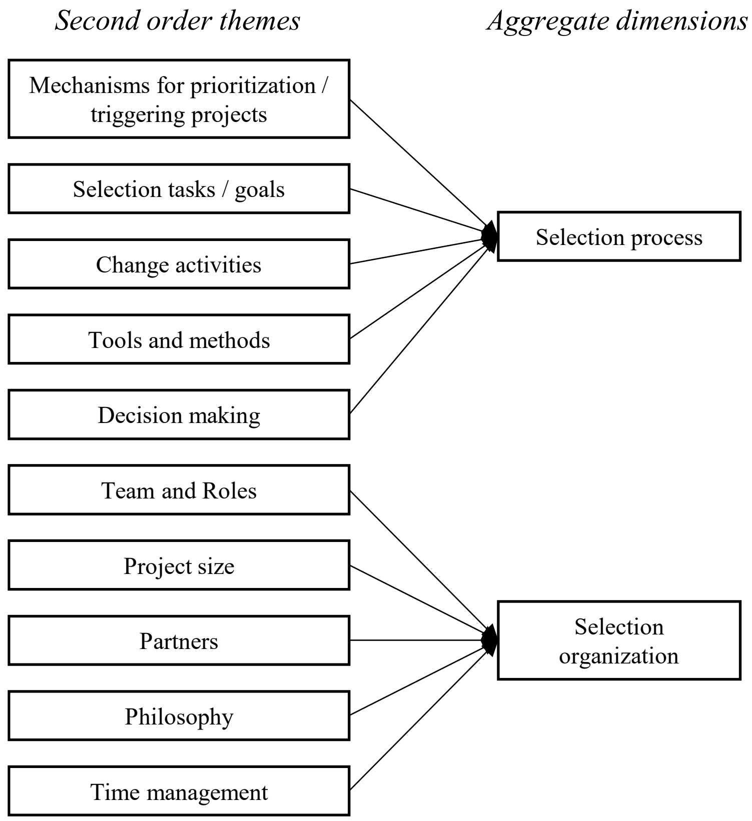

Figure 12: Response variables during the management of technology pre-adoption in supply chains[11]

Study A contributes to theoretical knowledge in technology adoption by questioning the best-practice paradigm and systemizing the problem-space of possible influencing factors and the corresponding solution space. This system enhances current literature by drawing a more holistic and contingent view on technology pre-adoption. Moreover, the research of study A is one of the few in the field to explore the topic empirically

Study A also contributes to practice in similar ways. The identified influencing and response variables system pose a practical guideline for supply chain managers when

[11] Figure 12 is extracted from study A.

setting up and conducting technology pre-adoption initiatives. In the broader context of this thesis, the overarching research phase utilizes the findings of study A and integrates the dimensions into an overarching approach. Thus, the theoretical system of influencing and response variables is transferred into an actionable tool. Thereby, study A aids in solving the managerial problem of approaching technology-related decisions systematically, as discussed in Section 1.1.

6.3 Study B: the anatomy of innovation problems

This section provides insights into the design-driven study on the problem side of technology-enabled process innovation, as conducted in study B. In the following, relevant contributions to theory, practice, and this thesis's overall goal are outlined[12].

Research design of study B

Researchers and practitioners often fixate on technologies when approaching innovation in supply chains. However, research suggests that a proper fit between technology and its environment is crucial for resulting performance outcomes. Thus, study B aims at achieving a proper understanding of the underlying innovation problems in supply chains, to theorize on the interplay of supply chain processes and technology. Therefore, the main goal is to systematize innovation problems in supply chain processes, considering potential technology deployment. Unfortunately, existing research seldomly provides theoretical or holistic contributions regarding technology deployment but rather specific performance impacts of individual technologies. Study B is among the first papers to explore the problem side of technology-enabled innovation in-depth. It thereby conceptualizes innovation problems holistically and lays the foundations for further theory-driven research to improve technology adoption decisions by understanding the interplay of technology and innovation problems.

The research was conducted in four main phases, centered around the seminal taxonomy development procedure proposed by Nickerson *et al.* (2013). These phases comprised (1) systematic literature review, (2) iterative taxonomy development, (3) taxonomy evaluation using expert interviews, and (4) taxonomy application. The primary data source of the paper was the systematic literature review, collecting relevant empirical papers on technology-enabled innovation in SCM. The review resulted in 127 relevant papers.

[12] Section 6.3 largely draws on extracts from the corresponding full paper in Appendix B.

Based on the systematically coded content of these papers, study B elaborated a taxonomy in five iterations. The resulting taxonomy was then discussed and revised with domain experts and applied to a real-world example. Finally, the evaluation illustrated the applicability and usefulness of the taxonomy.

Findings and contributions of study B

The main result of study B is a taxonomy describing the dimensions and characteristics of innovation problems in supply chains processes. The taxonomy consists of three main dimensions: (1) process specifications, (2) context specifications, and (3) innovation specifications. Process specifications describe the process itself and define the type of objects handled and the task to fulfill. Context specifications conceptualize the environment in which the process is embedded. They consist of the system complexity, organizational scope, hierarchy distribution, and the number of involved structures. Finally, innovation specifications refer to the process's aspired change and are defined by the innovation goal. Figure 13 provides an overview of the taxonomy with all dimensions and corresponding characteristics.

Dimensions		Characteristics				
Process specifications	**Object type**	Physical	Information	Financial	Legal	
	Object task	Creation	Transition	Storage	Verification	Modification
Context specifications	**System complexity**	Closed system	Controlled system	Open system		
	Organizational scope	Intra-organizational	Dyad	Triad	Network	
	Hierarchy distribution	Advantage initiating organization	Non-existent	Disadvantage initiating organization		
	Number of involved structures	Single (firm, dyad, triad, network)	Multiple (firms, dyads, triads, networks)			
Innovation specifications	**Innovation goal**	Enable process	Automate process	Accelerate process	Improve process output	Reduce process input

Figure 13: Taxonomy of innovation problems in supply chain processes[13]

[13] Figure 13 is extracted from study B.

Study B contributes to theory in three main ways: (1) it provides a better understanding of the problem space of the TTF model with particular regard to SCM, (2) it allows researchers to define and classify their unit of analysis precisely and thus has a high scientific utility, and (3) it provides a rigorous conceptualization of process innovation problems in supply chains concerning technology deployment by integrating and structuring existing knowledge.

The study also contributes to the managerial issues elaborated in Section 1.1. First, it offers a common understanding of the term process innovation problem, thus making the construct accessible to practice and supply chain managers. Second, building on the need for more detailed problem understanding, the taxonomy serves as a practical tool that facilitates systematic definition, comparison, evaluation, and analysis of process innovation problems.

Throughout this thesis, the taxonomy developed in study B and its contributions play a crucial role. First, study C relies on innovation problems' characteristics to describe real-world cases and collect data. The researched cases are classified using the elaborated taxonomy. Second, the study contributes to the overall research goal of the thesis to provide a practical approach to achieve process-technology fit. Thus, the overarching research phase integrates the taxonomy into the overall approach and transforms it into a practical, intuitively usable tool.

6.4 Study C: towards a process-technology fit in supply chain management

This section provides insights into the theory-driven research on the inter-relationship between types of innovation problems and technological solutions, as conducted in study C. Thereby, relevant contributions to theory and practice and for this thesis' overall goal are outlined[14].

Research design of study C

Supply chains are predicted to face severe disruptions due to emerging technologies like those summarized under *Industry 4.0*. By now, a high number of different technologies is available. As technology adoption consumes many resources, adoption decisions

[14] Section 6.4 largely draws on extracts from the corresponding full paper in Appendix C.

come into organizations' focus. Decision-making and adoption decisions regarding technology have a long tradition in innovation research and practice. However, a theoretical understanding of Industry 4.0 in supply chain processes and sensemaking of their benefits is still widely missing in the existing literature. Given this gap, TTF helps explain successful technology deployment in specific supply chain innovation problems.

More precisely, study C explores the interplay of real-world innovation problems and corresponding technology deployment that led to performance benefits, informed by TTF. Thereby, it follows a four-step research methodology: (1) development of an ex-ante framework informed by theory, (2) database creation through secondary research of empirical use-cases, (3) content analysis and quantitative clustering, (4) qualitative interpretation of the resulting clusters.

As mentioned above, the ex-ante framework poses an adapted fit model describing the interplay of supply chain technologies, innovation problems, and performance impacts. Based on the defined data points (informed by study B), a dataset of 79 unique empirical use-cases was created. Subsequently, the dataset was analyzed quantitively using hierarchical clustering algorithms in Python 3, leading to seven groupings of technology-enabled process innovations in supply chains. Lastly, the quantitively derived groupings were interpreted, enhanced qualitatively, and supplemented by additional research.

Findings and contributions of study C

Study C provides two primary constructs: (1) groupings of similar innovation problems in supply chain processes based on their constituting characteristics and (2) corresponding technological solutions and indications of their characteristics that lead to the successful innovation in each grouping. As a result, seven clusters of technology-enabled process innovation were identified:

- Cluster 1: *Enable inter-organizational flow tasks in open systems.*
- Cluster 2: *Enable information storage in and beyond organizations.*
- Cluster 3: *Create and transfer information along supply chains.*
- Cluster 4: *Improve output of information handling in organizations.*
- Cluster 5: *Improve the physical dimension in organizations and supply chains.*
- Cluster 6: *Automate physical storage on the organizational level.*

- Cluster 7: *Improve the physical transport in open systems.*

For each of the resulting groups, distinct patterns regarding the characteristics of deployed technologies have been identified, based on the characteristics provided by Goodhue and Thompson (1995).

Table 3 illustrates the associated technology characteristics for each grouping. The matching between technology characteristics and characteristics of each grouping (i.e., characteristics of the innovation problem) allows theoretical explanations of successful technology-enabled process innovation.

Table 3: Matching of technology characteristics and clusters[15]

Technology characteristics	Cluster 1: Enable inter-organizational flow in open systems.	Cluster 2: Enable information storage.	Cluster 3: Create and transfer information along supply chains.	Cluster 4: Improve output of information handling.	Cluster 5: Improve the physical dimension.	Cluster 6: Automate physical storage.	Cluster 7: Improve physical transport in open systems.
Data quality	++	0	++	++	+	0	0
Locatability of data	+	++	+	+	0	0	+
Authorization to access data	++	++	0	0	++	0	0
Data compatibility	++	++	0	+	0	0	+
Training and ease of use	0	0	++	0	0	+	0
Production timeliness	+	+	+	++	++	++	++
Systems reliability	++	+	0	0	++	++	++
IS relationship with users	0	0	++	++	+	++	0

Study C contributes to theoretical knowledge in two ways[16]. First, it provides a fundamental step towards connecting essential technological characteristics with innovation problems in supply chain processes. Second, the study proposes a supply chain-oriented process-technology fit model based on task-technology fit theory. From a practical perspective, study C reduces the complexity of Industry 4.0 applications because it breaks

[15] Table 3 is extracted from study C.
[16] For a more detailed elaboration of study C's contributions, consult Chapter 8 and Appendix C.

down different problems and solutions into seven manageable clusters. These clusters allow for clear communication on the topic, structured analysis of problems, and efficient solutions design.

The overarching research phase transfers these theoretical findings of study C into a practical method. The method facilitates categorizing real-world examples to one of the clusters and suggests best-practice technologies accordingly. Thereby, it enables organizations to fit their specific innovation problem with potential technologies.

7 Results

This Chapter presents the overarching results of the dissertation in detail, aiming to develop a method enabling systematic innovation through process-technology fit. First, Section 7.1 elaborates on the research design leading to the results, before Section 7.2 gives an overview of the developed method, comprising the *Supply Chain Process Innovation Grid's* structure and application possibilities. Last, Section 7.3 provides a detailed outline of each grid field.

7.1 Research design of the overarching results

This section provides insights into the design-driven research developing a method that enables organizations to radically or disruptively innovate their processes by achieving process-technology fit. The research design and a short summary are outlined shortly in this section, while the detailed results (i.e., the resulting method) are presented in the following sections.

External pressures force organizations to innovate their supply chain processes constantly. As a result, organizations seek to deploy technologies for radical or disruptive improvements in their processes, as the potential of incremental innovations such as continuous improvement has reached its limits (Lizarelli *et al.*, 2021). However, complex technology markets overburden decision-makers to find adequate solutions. Even more so, as performance goals are missed if the deployed technologies do not fit the context of a process (Autry *et al.*, 2010; Heine *et al.*, 2003).

The overarching research phase is concerned with problem-solving, which has a long tradition in academia. Current approaches in literature can be divided into either highly holistic approaches on the one hand or very specific and detailed approaches on the other. Holistic approaches are applicable universally and often have a long history of success in practice but at the cost of being abstract and needing intense adaption for specific problems. On the other hand, specific approaches fit a small portion of problems very well but can hardly be applied to other contexts. The literature review revealed a lack of specific approaches facilitating radical or disruptive process innovation in inter-organizational supply chain processes, especially considering process-technology fit. However, some holistic approaches like Systems Engineering, Collaboration Engineering, or Design Thinking can aid systematic process innovation if specified accordingly.

The overarching research phase of this dissertation aims to fill this lack in specific approaches to systematically achieve radical or disruptive innovation and process-technology fit. Therefore, it integrates the knowledge of studies A, B, and C and existing problem-solving approaches, designing a specified approach for the given problem. Thereby, it mitigates the shortcomings of established approaches. The study follows the Design Science Research (DSR) approach, which is highly used in IS and business innovation research (Winter and Aier, 2016). Simply put, DSR aims at pragmatically designing useful artifacts to solve relevant problems. This research approach suites the given problem for three reasons:

- *High focus on the research outcome* (Hevner, 2007): Studies A, B, and C have a theoretical and explorative focus, while the overarching research phase aims at practical outcomes that can be applied directly.
- *A structured process for generating knowledge drawn from different information streams* (Hevner *et al.*, 2004): Different information streams refer to literature, empirical data, and the findings during different studies conducted as part of this thesis, which are integrated into the overarching results.
- *Provide innovative solutions to problems from practice with the overall objective of usefulness* (Hevner *et al.*, 2004): Practical usability and usefulness are the main goals of the overarching research, as the theoretical foundations have been laid in studies A, B, and C.

Four artifact types can be distinguished in DSR research: constructs, models, instantiations, and methods. In this context, methods describe a series of steps to achieve a specific task or recipes to solve given problems with the help of specific instructions (March and Smith, 1995). Thus, methods are a highly suited artifact type for the given problem statement. Hevner (2007) proposes an iterative, three-cycled approach to design useful artifacts pragmatically but rigorously at the same time. An overview of this deployed DSR approach is given in Figure 14. The cycles and their specific implementation are as follows:

- *Relevance cycle*: The relevance of an artifact is grounded in the improvement of its environment. The relevance cycle thus analyzes the artifacts' environment to ensure the practical relevance of the results. Essential activities in this phase involve identifying the main practical problem at the beginning and returning the artifact into the environment to identify shortcomings at the end. As for all of the cycles, the relevance cycle should be performed multiple times iteratively.

- *Rigor cycle*: The rigor cycle examines already existing knowledge about the artifact. It thus poses the theoretical counterpart to the practice-oriented relevance cycle. Results of the rigor cycle are summarized as the *knowledge base*. The resulting artifacts can be interpreted as an addition to this existing knowledge.
- *Design cycle*: The design cycle poses the central part of DSR, as it comprises the building, evaluation, and refinement of the artifact (March and Smith, 1995). The design cycle is highly interdependent with the relevance and rigor cycles, as it directly draws from their findings. The cumulative character of this thesis corresponds with the DSR approach suggested by Hevner (2007). Usually, the DSR approach starts with a detailed literature review on the relevant topic. In this thesis, the literature review conducted in Chapter 3 on technology pre-adoption, innovation in inter-organizational processes, and fit literature builds the theoretical knowledge base. The DSR approach allows explicitly for multiple sources of information. Thus, the isolated analysis in studies A, B, and C can be integrated into an overarching method.

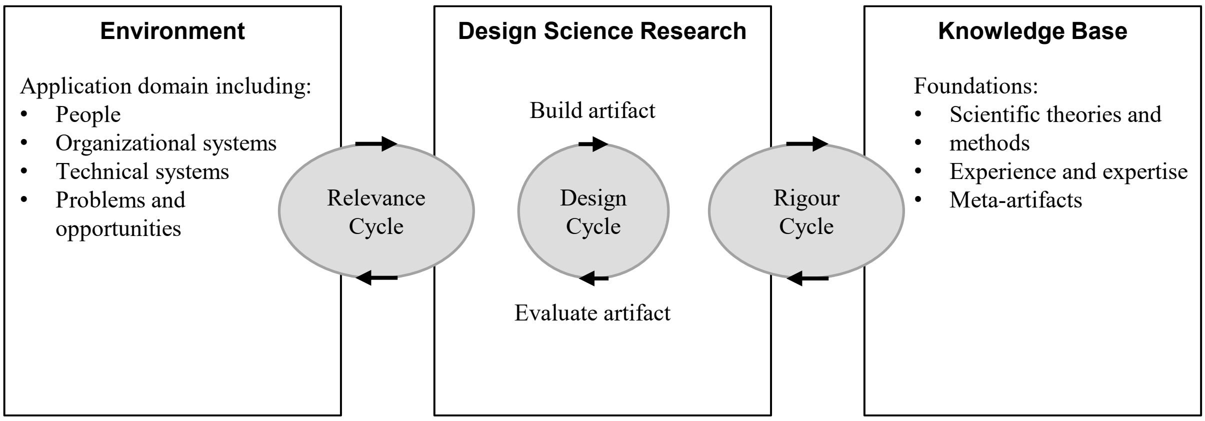

Figure 14: General DSR three-cycle approach as suggested by Hevner (2007)

Regarding the precise implementation of the general DSR approach, the overarching research followed the recommendations given by Hevner (2007). It pursed an iterative design process through the steps: relevance cycle, rigor cycle, design cycle, as outlined in Figure 15. When executing the DSR cycles, the first step is the explicit formulation of the problem statement that defines the research objective. This step is located in the relevance cycle to ensure practical importance. As stated above, this refers to the missing approaches or methods to systematically enable organizations to innovate their supply chain processes and achieve process-technology fit. Furthermore, the problem was specified to radical or disruptive innovations.

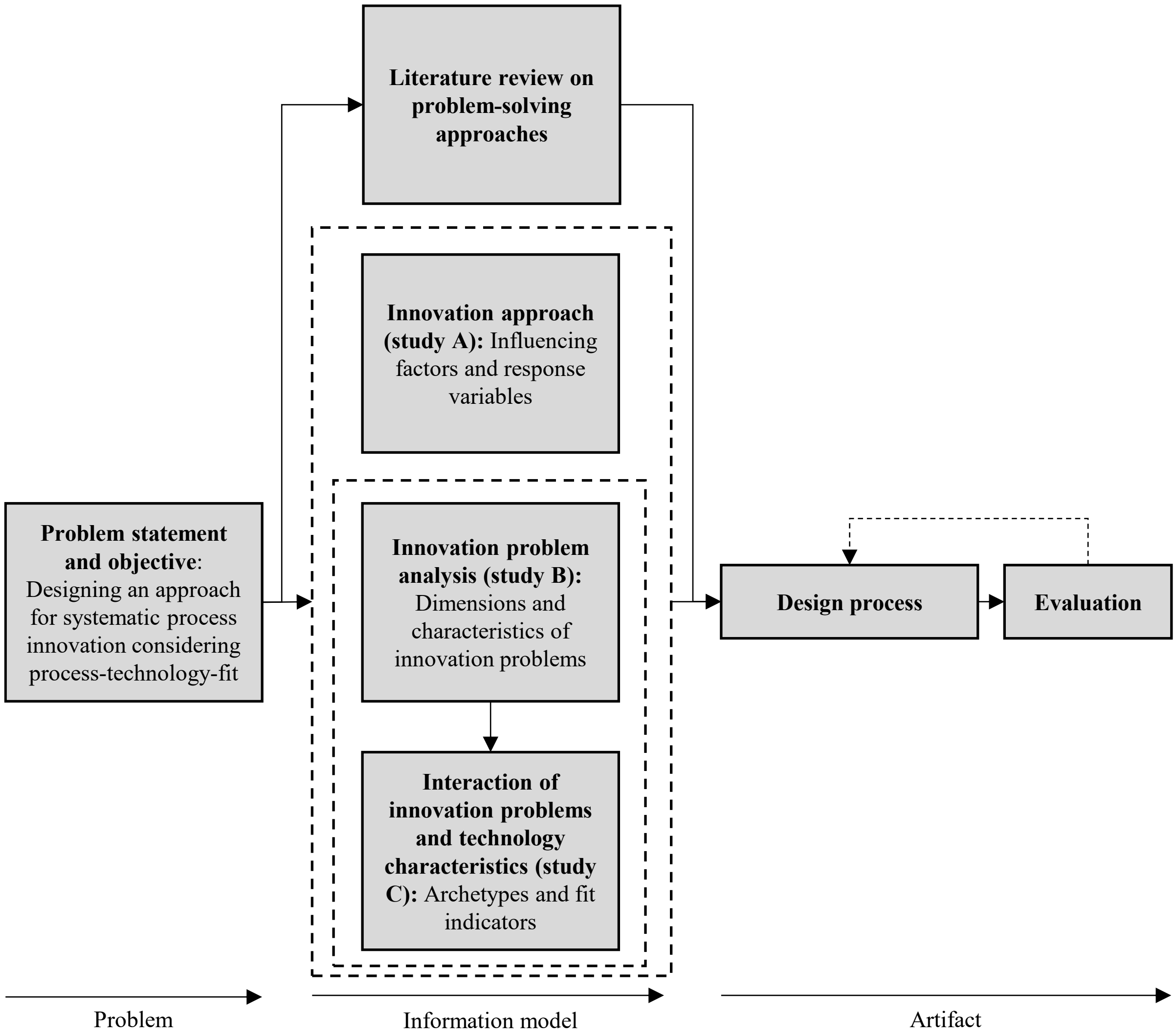

Figure 15: Specified DSR-approach for the overarching research phase

This specific practical problem was identified based on informal conversations with practitioners involved in digitalization projects of their organizations, semi-structured interviews as part of study A, and project work conducted in cooperation with organizations from 2018 to 2020 as part of a research project. During the rigor cycle, the innovativeness of the research must be ensured, and the knowledge base is searched for valuable inputs to contribute to the artifact's design. Therefore, the rigor cycle comprised a literature review on problem-solving approaches and methods suited for technology identification and selection. The design cycle comprised many iterations between designing and refining the novel approach and evaluation versus the knowledge base. After the designed method met the researcher's standards, it was evaluated more closely, consulting empirical data gathered from study A and related project work.

7.2 Overview of the Supply Chain Process Innovation Grid

The dissertation proposes a method that enables organizations to systematically innovate their supply chain processes in a radical or disruptive manner. This method is based on the detailed findings of studies A, B, and C and was designed in a separate, methodologically rigorous process. During this research process, supplementary literature and data were identified and used. Contrary to studies A, B, and C, which had a high theoretical focus, this overarching research strongly emphasizes the resulting method's practical usefulness and direct applicability.

Goal and structure of the Supply Chain Process Innovation Grid

The proposed method is dedicated for usage by supply chain practitioners after the first indication of an innovation problem has emerged. Thus, situations the organization has identified as an opportunity or need for improvement in a specific inter-organizational process pose the starting point of the proposed method.

Based on this initial innovation problem setting, the Supply Chain Process Innovation Grid supports systematic analysis, goal formulation, solution search, and evaluation and selection of solutions to deploy technologies that ultimately fit the process's characteristics. These main steps of the method are adapted from the widely-known Systems Engineering approach and pose the first central dimension of the grid. The literature review revealed that some holistic methods and approaches for problem-solving and systems development have high potential and a proven record in practice (Haberfellner *et al.*, 2019). A comparing analysis showed that Systems Engineering's characteristics fit the given problem very well for the following reasons:

- It poses a highly structured approach regarding the steps performed, which fits the need for a systematic approach towards innovation (Haberfellner *et al.*, 2019).
- Despite its clear structure, it leaves many degrees of freedom regarding how different steps are performed in detail and leaves some opportunities to enhance the

agility of the approach, e.g., by iterating over the steps of the problem-solving cycle (Haberfellner *et al.*, 2019).

- It provides a *school of thought* as part of its philosophy that facilitates working with complex systems and solutions, and inter-organizational processes and emerging technologies fall into these categories (Haberfellner *et al.*, 2019).

Although these characteristics make it generally suitable to guide process innovation in supply chains, Systems Engineering lacks specific consideration for inter-organizational processes and technology deployment. Thus, the approach can only serve as a structuring guideline that must be specified based on the findings of this thesis. The four steps of the Systems Engineering problem-solving cycle play a crucial role in the resulting method and are thus explained shortly in the following:

- *System analysis* poses the first step of the problem-solving approach that follows the initial identification of the innovation problem. The system analysis goals are to understand the problem with special consideration of the problem's scope and its embedding in the environment. It lays the basis for formulating goals and searching for solutions (Haberfellner *et al.*, 2012).
- *Goal formulation* handles the fundamental question of *what are we trying to achieve?* Some form of goals is often already included in the initial innovation problem. Moreover, the situation analysis reveals important and concrete goals for the innovation problem. Goal formulation is also related to solution search, as it resolves conflicting goals between different stakeholders and focuses on the subsequent solution search. The goal formulation phase thus acts as an integrating factor between initial problem and solution search (Haberfellner *et al.*, 2012).
- *Solution search* poses the phase of creatively designing and analyzing potential solutions for the initial innovation problem. It directly relates to the results of a situation analysis and goal formulation. Expertise and creativity are two main drivers of successful solution search. Systems Engineering suggests the design of different versions of solutions to decide from instead of early engaging in one specific solution (Haberfellner *et al.*, 2012).
- *Evaluation and decision-making* mark the last phase in Systems Engineering's problem-solving cycle. It comprises the evaluation and decision-making

regarding the solution. During the evaluation, different versions are assessed based on the given criteria. The goal formulation phase directly informs these criteria. Following the evaluation, a decision regarding the project's further development arises. Decisions with far-reaching impact should always be supported methodologically (Haberfellner *et al.*, 2012).

It is worth mentioning that besides the four problem-solving steps, Systems Engineering provides a meta-process to put different projects or studies in a broader context. It differentiates between preparatory studies, main studies, and detailed studies (Haberfellner *et al.*, 2012). This differentiation makes sense to draw a complete picture of system development projects, from gaining access and direction to a problem towards detailed solutions design. However, in practice, seldomly all of these studies are conducted explicitly in a structured manner.

The Supply Chain Process Innovation Grid has the character of a preparatory study in this regard and leaves the other studies out of scope to be solved by traditional Systems Engineering or other approaches. Therefore, the proposed method is a structured, detailed, and specific guideline to execute the preparatory study of an innovation problem in a supply chain process. Figure 16 illustrates different abstraction levels of technology decisions. The proposed method is concerned with problems related to *technological applications*. The preparatory study results in answers for the two main questions:

- During the subsequent studies, which technological applications should be focused on for this specific problem?
- How must the management activities and organization be designed to address the problem during the subsequent studies?

Resulting from the preparatory study as suggested by this method, a decision on which technological applications can solve the innovation problem evolves. Subsequently, main studies have to be conducted separately. These studies then comprise the specific design or customization of the technological solution and the evaluation of different solution providers. Lastly, detailed studies must specify very detailed aspects like technical interfaces of systems and first prototypical implementations.

Specific

Abstraction level	*Exemplary characteristics*	*Related selection decisions*
Technological solutions: Specific technological products for a concrete context, Example: analytics tool for the sourcing process using a software of a certain provider	• Available vendors and vendor characteristics (e.g., product offering, pricing structure, quality)	• Which solution and vendor are to chose for a specific problem?
Technological applications: Combination of one or more industry 4.0 key technologies building a specific solution or product than can be used in different contexts, Examples: augmented reality glasses, autonomous drones	• Defined form and functionalities • Abstract situation of technology market • Specific functions and deployment areas in SCM	• Which application can generally solve a specific problem?
Key technologies: Abstract building blocks of technology infrastructure Examples: IoT, cloud computing, distributed ledger technology	• Abstract functions • Abstract benefit propositions like interconnection, transport, transactions, transparency	• Which key technology can address the problems regarding their abstract functions and proposed benefits?
Base technologies: Fundamental technical principles regarding sensors and actuators, communi-cations, data storage and processing Example: sonar sensors	• Fundamental functionalities • Underlying fundamental physical mechanisms	• Which basic technologies is the solution based on? • Are there interoperability problems on base technology level?

Abstract

Figure 16: Abstraction levels of technology decisions

The second dimension of the method's framework stems from the socio-technical-systems theory (Section 5.5). It differentiates between the social system of the innovation problem (i.e., the structures and people involved) and the technical system (i.e., the technologies and processes involved). The individual studies and their empirical evidence have shown that technology initiatives are seldom solely about technology. Technological capabilities progress and technological systems' implementation becomes more manageable than before. Thus, integrating technologies with their social surroundings becomes crucial for technology adoption. In their seminal work on socio-technical systems, Bostrom and Heinen (1977) stated that organizations and processes are highly complex combinations of technical and social systems. Thus, a method for achieving process-technology fit must explicitly address both the social and the technical system and ensure their fit with each other.

The differentiation between social and technical systems plays an essential role in the Supply Chain Process Innovation Grid. Thus, the main aspects and the specific transfer for supply chain innovation problems are elaborated on in the following. It is worth mentioning that although the differentiation is grounded in theoretical work, some adaptions and interpretations were made to ensure the practicability and usefulness of the resulting method.

- *Social systems* comprise people and structures (Bostrom and Heinen, 1977). People include the employees affected by the innovation problem and the process innovation. The people's knowledge, skills, attitudes, values, and needs in the work environment are also included under the people dimension. Structures of the social system refer to reward systems or authority structures of the specific setting in the organization. Some research on socio-technical systems has an even broader view and includes customers, suppliers, and regulations into the social system (Heller, 1997). This broad view is adapted for the developed method as it aids in modeling the inter-organizational setting of supply chain processes.
- *Technical systems* comprise processes and technologies (Bostrom and Heinen, 1977). These processes[17] refer to the organization's transformation of input into valuable outputs. Technologies refer to all kinds of devices, tools, or techniques that support this value creation process.

As stated in Section 5.5, harmony between the social and the technical system is a vital issue in technology adoption and a cornerstone of socio-technical theory. Applied to the setting of this thesis, the theory states that innovation problems can only be solved successfully if the interdependence of the social and the technical sub-system of the process is explicitly recognized. Furthermore, researchers have stated the need for design approaches to understand the inter-relationship of different sub-systems and methods that facilitate harmonization (Cherns, 1976). Therefore, the suggested method explicitly enforces harmonizing the two sub-systems of the innovation problem in each phase of the

[17] In the original source, the technical system comprises *tasks* and *technologies*. As outlined in section 2, this thesis views tasks as lower-level sub-processes and does not explicitly delineate between the two.

problem-solving cycle. Figure 17 provides an overview of the Supply Chain Process Innovation Grid, including its main dimensions and essential activities in each field.

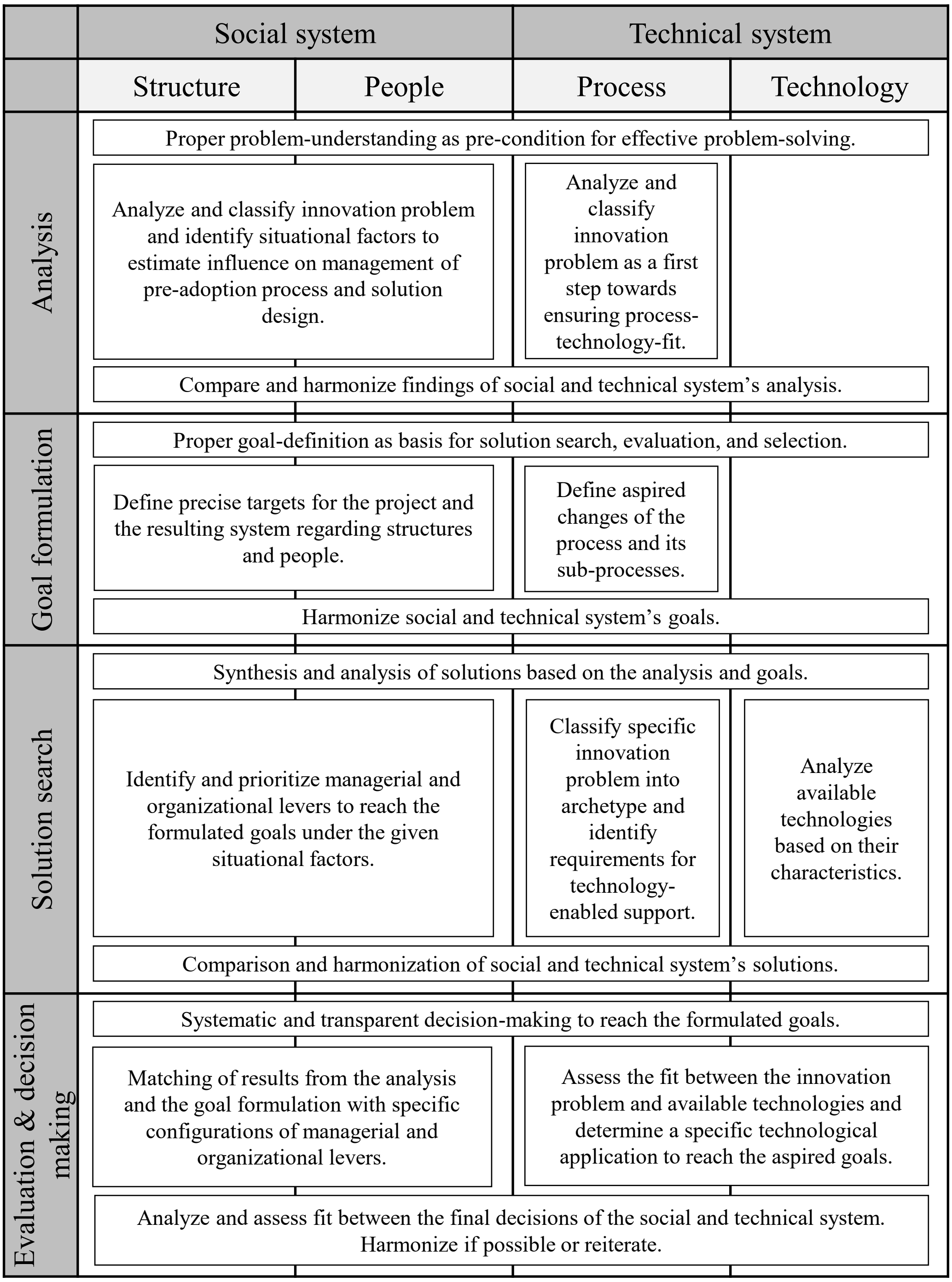

Figure 17: Overview of the Supply Chain Process Innovation Grid

Application of the Supply Chain Process Innovation Grid

Working with the proposed Supply Chain Process Innovation Grid consists of two main phases: preparation and execution. The preparation phase is a meta-analysis of the situation and determines how the innovation grid must be deployed. While the Supply Chain Process Innovation Grid itself is static in its content, the application can follow different paths depending on the specific problem at hand. Figure 18 illustrates possible paths through the grid.

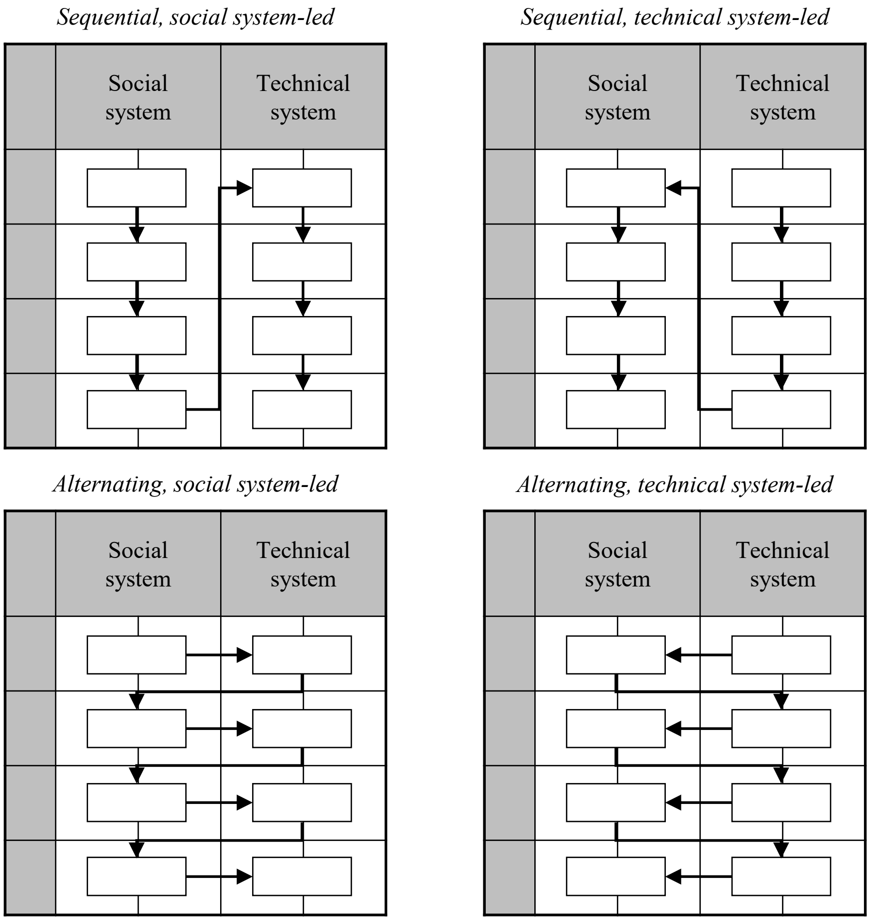

Figure 18: Overview of options to apply the Supply Chain Process Innovation Grid

The sequential approach executes all steps for one of the sub-systems first and then for the other. Harmonization between the sub-systems is conducted iteratively when the initial situation, goals, and solutions are elaborated to a relatively detailed level for both sub-systems. The alternating approach executes each step for both sub-systems before proceeding to the next one. Thus, harmonization between the sub-systems is ensured directly after each step. Moreover, both approaches execute the steps for one sub-system first, and thus one sub-system plays a leading role in the overall process. Figure 19 provides arguments and recommendations for selecting a path through the grid. However, these paths only provide a general guideline for approaching the problem. Depending on the results of each phase, especially comparison and harmonization between different systems, re-iterations of individual phases may be necessary. Therefore, the grid allows for a high degree of flexibility and agility in its application.

	Technical system-led	Social system-led
Sequential	Sequential, technical system-led: • Technical system in focus • No restrictions to technical system, social system adapted afterwards • Isolated design of technical system bares risk of inconsistencies with social system → Recommended when social impact is estimated to have limited impact on overall innovation problem and technical system plays the essential role. Social system can adapt to technical requirements.	Sequential, social system-led: • Social system in focus • No restrictions to social system, technical social system adapted afterwards • Isolated design of social system bares risk of inconsistencies with technical system → Recommended when social system has major impact on the overall innovation problem and is crucial for the problem-solving success. Technical system adapts to social requirements.
Alternating	Alternating, technical system-led: • Alternation leads to incremental harmonization during the process and thus minimizes the risk of inconsistencies or sunk time into one of the systems during the method application. → Recommended when both systems are similarly important and similar hard to change. Leading role for the technical system if higher technological focus.	Alternating, social system-led: • Alternation leads to incremental harmonization during the process and thus minimizes the risk of inconsistencies or sunk time into one of the systems during the method application. → Recommended when both systems are similarly important and similar hard to change. Leading role for the technical system if higher social focus.

Figure 19: Situational recommendations for applying the Supply Chain Process Innovation Grid

7.3 Outline of the Supply Chain Process Innovation Grid

After an overview and options for applying the Supply Chain Process Innovation Grid have been given in Section 7.2, Section 7.3 provides a detailed description of the method's steps: *analysis, goal formulation, solution search,* and *evaluation and selection.*

7.3.1 Analysis of the innovation problem

The Systems Engineering approach emphasizes a proper problem understanding at the early stages of a project, as it lays the foundation for all the subsequent phases (Haberfellner *et al.*, 2012). Therefore, the following subsection elaborates on the detailed analysis of the social and technical system. Thereby, it explains the focus of the analysis and the main activities and provides a specific method or tool for each of the sub-systems' analysis.

Social system analysis

The social context of the initial innovation problem has a significant impact on two main aspects: (1) the design and management of the pre-adoption procedure and (2) the design of the resulting solution. The first aspect is emphasized in this method explicitly and focused because the individual technology pre-adoption approach must be designed carefully to result in successful and efficient outcomes. Moreover, successful and efficient pre-adoption is highly dependent on different influencing factors, as study A indicated.

The second aspect handles the influence of the social system on the solution design. Thus, it is essential to systematically identify and classify the initial innovation problem during the analysis phase. Furthermore, this information will be necessary during the harmonization between the technical and social systems in the later stages of the approach, namely during solution search. As stated earlier, the technical system needs to fit the characteristics of the social systems. Thus, the initial characteristics of the social system have to be determined. To sum up, characteristics of the social system have a significant influence on both pre-adoption management design and solution design. Thus, this part of the Supply Chain Process Innovation Grid offers a specific tool to systematically identify and classify the characteristics of the initial innovation problem's social system.

The Systems Engineering approach, as described by Haberfellner *et al.* (2012), relies on the very effective system analysis and system delineation method to determine what aspects of the problem are changeable, which ones are to consider but not to change, and which ones are out of scope. After relevant elements have been identified and classified, their relationships are drawn out. As mentioned earlier, Systems Engineering does not prescribe specific detailed ways to analyze the initial situation but instead emphasizes the necessity to do so and the goals to be achieved. In practice, often recognized frameworks such as the PESTEL-analysis structure the situation analysis and system delineation (Haberfellner *et al.*, 2019).

For analyzing and characterizing the innovation problem's social system, the Supply Chain Process Innovation Grid proposes the specific structure as illustrated in Table 4.

The table poses an operationalized and extended version of the results of study A[18]. Practitioners can use the table as a questionnaire to determine and document the relevant characteristics of the social system's initial situation.

Table 4: Questionnaire to analyze the innovation problem's social system

		Second-order themes	**Questions**	**Answers**
Firm-specific	Criticality	Investment	How high is the impact of necessary investments for the organization?	• Very low or no impact • Low impact (smaller than most projects) • Considerable impact (same or more than most projects) • Substantial impact (higher than most projects)
		Relevance for main business activity	How is the main business activity of the organization influenced by the problem?	• No relevance for main business • Moderate impact (e.g., efficiency gains, minor improvements) • High impact: problem relates to organization's core business (e.g., new service offering)
		Financing	What is the source of the organization's and project's funding?	• Equity • Debt
	Problem type	Origin of problem	Does the problem originate from inside the organization or from an external trigger (e.g., customer, supplier)?	• Internal • External
		Time reference of problem and management sphere	What timeframe and what hierarchical management sphere is the problem located?	• Operational • Tactical • Strategic
		Abstraction level of problem	In which form was the problem identified?	• Specific problem description • Vague notion of issues
	People	Competence and motivation	Do the affected employees have specific competencies regarding problem-solving, technology, and project management? Are they committed to changing the current status?	• High competencies and high motivation • High competencies but low commitment or even resistance • Low competencies but high motivation • Low competencies and low motivation
		Culture	What is the organization's or department's culture? For example, is change, agile work, and technology part of the culture? Do hierarchy and defined structures and processes define the organization?	• Traditional: High levels of hierarchy and bureaucracy • Agile: High levels of entrepreneurship, low levels of bureaucracy and hierarchy
		Size of the affected organization	What is the organization's or department's size, the problem is located?	• Multi-national corporate • National corporate • Small or medium company • Startup

[18] A detailed description of the method and the results are given in study A in the Appendix.

Table 4 (continued)

		Second-order themes	Questions	Answers
Firm-specific	Criticality	Affected departments	How many and which of the organization's internal departments are affected? How complex is it to find common ground on decisions and gather information? How are affected departments distributed geographically?	• Low complexity: Only initiating department and some loosely related stakeholders • Medium complexity: Initiating and few other relevant internal stakeholders. Close geographical distribution • High complexity: High number and high relevance of internal stakeholders, globally distributed
Network-specific	External complexity	Affected external departments	How many external departments are affected by the problem? How and how intensely must they be involved? Are there cultural differences between the organizations?	• Low: No external stakeholders involved • Medium: Low number of external stakeholders, primarily informative involvement • High: High number of external stakeholders with intense collaboration
Network-specific	External complexity	Geographical specifications and footprint	What is the geographical scope of the problem? Do geographical distances affect the problem? Are different regulations or specifications relevant?	• Low: Low geographical distances and homogenous regulations • High: High geographical distances and heterogenous regulations
Network-specific	Strategy	Strategic cooperation	Is current strategic, long-term cooperation with supply chain partners affecting the problem?	• Yes: Current strategic cooperation aid in solving the problem and must be considered • Yes: Current strategic cooperation hinder solving the problem and must be considered • No: The problem can be addressed independently
Environmental factors	Technology market characteristics	Cost structure of technology	What costs are involved when accessing a specific technology? How exactly do these costs occur?	• High initial cost, high running cost • High initial cost, low running cost • Low initial cost, high running cost • Low initial cost, low running cost • Free access
Environmental factors	Technology market characteristics	Availability and diversity of solutions, vendors, partners	How attractive is the technology market from a buyer's perspective? How complex is the technology market?	• High complexity: Low number of suitable suppliers, hard to identify them, low negotiation power of the buyer • Low complexity: High number of suitable suppliers, easy access, high negotiation power
Environmental factors	Industry regulations	Process regulations	Are there mandatory requirements for conducting technology projects in the industry?	• Yes • No
Environmental factors	Industry regulations	Documentation requirements	Are there mandatory requirements for documenting technology projects in the industry?	• Yes • No
Environmental factors	Industry regulations	Solution restrictions	Are specific types of solutions prohibited or prescribed by industry regulations?	• Yes • No

It is important to note that this questionnaire comprises both the people and the structure of the social system, and it does not sharply delineate between them. However, both dimensions and their main aspects are included in the tools and discussed shortly.

The people dimension is a significant influencing factor and highly relevant for the initial innovation problem for two reasons. First, people have a high impact on how the pre-adoption process must be designed. Therefore, it is necessary to assess the skills and motivations of the involved employees. More precisely, the people who will participate in the initiative have to be analyzed. Second, people play a crucial role in the questionnaire's internal and external affected departments dimension. More precisely, people that do not play an active part in the initiative but must comply with specific goals and activities or provide necessary information or support during the process must be analyzed.

The other dimensions of the questionnaire mainly refer to structures in place, either in the organization itself, in the supply chain setting, or the industry or environment as a whole. It is worth mentioning that these structures also have interdependencies with the people. Overall, the questionnaire in Table 4 thus serves as an actionable tool for integrative analysis of the innovation problems social system, including the relevant structures and people.

Technical system analysis

The technical system of the innovation problem consists of the analyzed process, including its sub-processes and the technologies deployed. The Supply Chain Process Innovation Grid focuses on analyzing the process part of the technical system. From an abstract perspective, the process manifests a business need of the organization that has to be performed (Davenport, 1993). Thus, identifying this abstract business need is crucial for designing efficient processes. The thesis views this business need as fixed rather than changeable. On the contrary, technologies and technological infrastructure can be interchanged quickly and are thus handled during the solution search so that they are out of focus in the analysis phase.

As stated earlier, research revealed that technology deployment only leads to the expected performance outcomes if it fits the environment it is deployed in (Goodhue and Thompson, 1995). Thus, a proper understanding of the innovation problem is the first step to achieving a fit between the process and potential technological solutions. Study B revealed a set of dimensions and characteristics most important to analyze when technologically innovating a given process. Based on these findings, an innovation problem canvas was built to facilitate the analysis of innovation problems in practice, as illustrated in Figure 20.

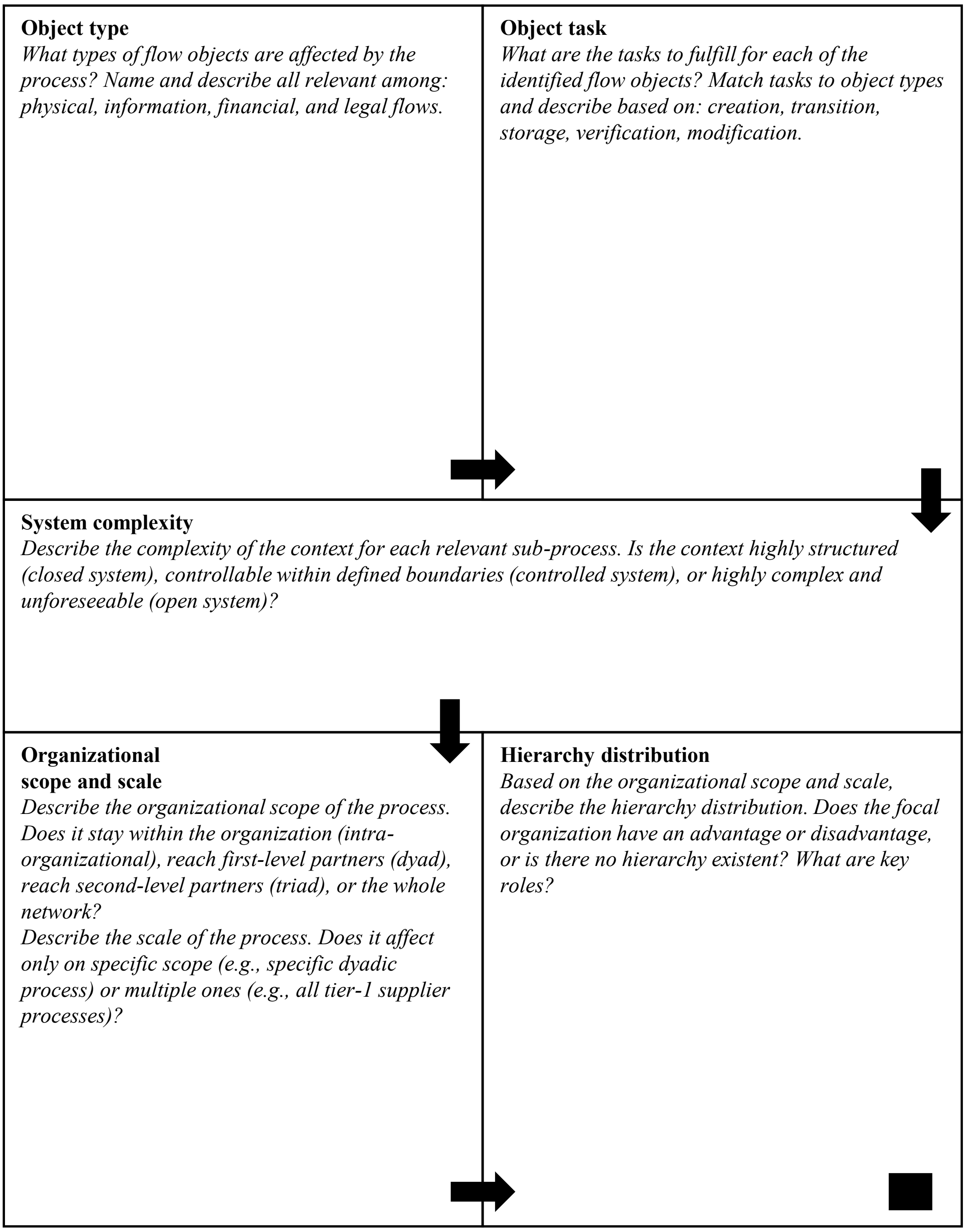

Figure 20: Innovation problem canvas for supply chain processes

The usefulness of this canvas is twofold. First, it allows a sharp classification of individual innovation problems. This classification is the basis for later categorization into a cluster and matching potential technologies during solution search. Second, the canvas serves as a medium for systematic qualitative analysis of innovation problems. Besides strict classification, practitioners should elaborate each of the canvas' fields qualitatively so that the canvas is used to elaborate, store, and communicate the analysis of the innovation problem in and beyond the organization.

Harmonization of the social and technical systems' analysis

After the sub-systems' individual analysis, an integrated examination of the findings must be conducted. Thereby, essential inter-relationships and restrictions between the two sub-systems need to be identified. In practice, this issue can be addressed by discussing each sub-system's analysis findings with relevant stakeholders of the other sub-system or re-iterating findings in workshops.

7.3.2 Goal formulation for the innovation problem's solutions

Goal formulation poses a significant aspect of the Systems Engineering solution cycle because it is crucial to define precise and exhaustive goals for every aspect of the solution. Goals are elaborated based on the situation analysis and build the basis for evaluating and selecting potential solutions in the following phases. Four types of goals can be differentiated (Haberfellner *et al.*, 2012; Autry *et al.*, 2010):

- *Must-have goals*: The solution must have a specific characteristic or fulfill specific criteria.
- *Restricting goals*: The solution must not exceed or fall below a particular value in a goals dimension.
- *Nice-to-have goals*: The solution is rated better if it has a specific characteristic or fulfills specific criteria.
- *Optimization goals*: The higher or lower the values in a specific goal dimension, the higher the solution's rating.

For the context of technology-enabled innovation in supply chain processes, the Supply Chain Process Innovation Grid moreover distinguishes two types of goals: (1) project goals and (2) system goals. Project goals refer to the process that leads toward the ultimately designed system (i.e., the technology pre-adoption approach), whereas system goals refer to the solution itself (i.e., the implemented technology and its environment). Project goals mainly address the social system of the innovation problem. Therefore, they are related to the style and organization of the technology pre-adoption procedure to achieve specific outcomes. However, they are also intertwined with the technical system as the ultimate goal of the pre-adoption process is performance enhancement through technology deployment.

System goals address both the technical and the social systems. The central aspect is the technical system, as it focuses on the design of the solution. However, as the technical system and the resulting solution are highly interdependent with the social system, the technical system goals also have to consider the social aspects. The Supply Chain Process Innovation Grid proposes a practical framework for defining the goals of both the technical and the social systems. Interdependencies of the systems are addressed by overlapping dimensions in each set of goal dimensions and by harmonizing the goals at the end of the goal formulation phase.

Social system's goals

The main goal dimensions of the social system can be illustrated on a scale of project and system goals. Study A identified four main dimensions of measuring the success of technology pre-adoption with touchpoints to project and system goals[19]:

- *Pre-adoption efficiency*: How much resources does the pre-adoption procedure itself consume concerning the outcome? This dimension purely refers to the output of the pre-adoption management and organization under consideration of specific inputs.
- *Adoption success*: Did the pre-adoption process lead to successful implementation in the organization? It is important to note that this dimension relates to implementing the solution as the proceeding phase after the pre-adoption. The research found that the better the pre-adoption process, the higher the chances for successful implementation. For example, an excellent pre-adoption process will sort out unrealistic solutions that might lead to unsuccessful implementation or conduct thorough planning early on, facilitating implementation (Selensky and Hofmann, 2020b).

[19] Detailed information on the identified goals and their inter-relationships can be found in study A in Appendix A.

- *Acceptance and utilization*: Are all relevant stakeholders accepting the resulting solution and utilizing its full potential? This question poses the central aspect of the social system's goals. It is located at the interface of process and project goals and cannot be analyzed separately. Acceptance and utilization are measured after implementing the resulting solution, but the pillars for acceptance and utilization are built during the pre-adoption phase (Selensky and Hofmann, 2020a). For example, specific change activities and stakeholder involvement during the pre-adoption process significantly impact the acceptance and utilization of the technical solution (Selensky and Hofmann, 2020b).
- *Effectiveness*: Does the resulting solution provide the outcomes and the performance as planned? This dimension mainly refers to the technical system itself. However, as the goal of the pre-adoption process is to identify and select technically effective solutions, effectiveness also ultimately measures the quality of the pre-adoption process.

These are the four main dimensions of social system goals on a holistic level. In practice, additional operationalization of each dimension is necessary, considering the organization's situation. Specific sub-goals must be formulated using one of the beforementioned goal types for each dimension. Besides the goal types, these specific sub-goals must include a metric, a numeric target, and a time constraint for when the goal is to be reached (Haberfellner *et al.*, 2012). For example, for pre-adoption efficiency, an exemplary input and output could be operationalized with a fixed budget in a given currency (i.e., numeric target and metric) for the pre-adoption process. Moreover, a set deadline (i.e., time constraint) could pose a restriction goal for the input.

Technical system's goals

As defined earlier, processes transform a specified input into an output of higher value (Davenport, 1993). Thus, technology-enabled innovation can improve either the input, the output, or how the value creation process is executed in between. Based on these considerations, five generic characteristics describing the holistic goals of technology deployment in supply chain processes are derived (Selensky and Hofmann, 2021): enable a process, accelerate the process, automate the process, improve the process output, reduce the process input[20]. Figure 21 illustrates the inter-relationships between the different innovation goals.

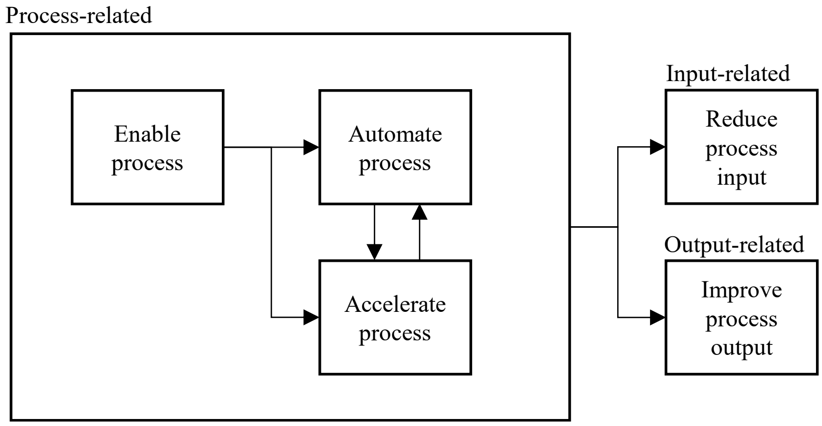

Figure 21: Overview and inter-relationships of the technical system's goals[21]

- *Enable a process* refers to technologically facilitating a process that was not possible to execute in that specific way before. For instance, this applies to collecting new data types due to modern sensor technology (Winkelhaus and Grosse, 2019b).
- *Accelerate the process* refers to the speed and timeliness of a process, e.g., how fast data is available at a desired location or supply chain actor (van Hoek, 2019b).
- *Automate the process* refers to the degree to which manual interference is necessary to perform a process. For example, physical handling effort or human interaction during information exchange between supply chain partners fall into this category (Wamba, 2012; Hellstrom and Wiberg, 2010).
- *Improve the process output* refers to the result of the process regarding quality, amount, or other relevant measures of value. Examples are data accuracy or the financial outcome of specific processes (Brinch *et al.*, 2018; Engelseth and Wang, 2018).

[20] Detailed information on the identified goals and their inter-relationships can be found in study B in Appendix B.
[21] Figure 21 is extracted from study B.

- *Reduce the process input* refers to the resources required to perform a particular process, e.g., making it more efficient or sustainable (Yang, 2019).

These are the generic goals for improving the process of the technical system using technology. These generic goals must be prioritized and specified in a two-step approach during practical application. First, the primary goals must be identified out of the five dimensions. Usually, one main goal is the trigger of the innovation problem. Second, for the main goals, specific sub-goals need to be defined following the goal formulation approach of Systems Engineering, including goal types, metric, numeric target, and time constraint (Haberfellner *et al.*, 2012).

Harmonization of the social and technical systems' goal formulation

As stated above, the social and technical system's goals are highly interdependent. The overlapping dimensions of the social system's goals (i.e., acceptance, utilization, effectiveness) already account for that interdependency somehow. However, after the specific sub-goals are formulated for each system individually, they should be compared and reflected against each other. This way, opposing goals or a diverging focus in different goal dimensions can be identified early. Also, this comparison poses a step for different stakeholders (e.g., technical staff and project management) to understand all aspects of the initiative better.

7.3.3 Solution search to resolve the innovation problem

The solution search builds upon the knowledge gained from the analysis and the goal formulation phase. It can be divided into synthesis and analysis of solutions. During synthesis, a wide variety of solutions is searched. During solution analysis, solutions are pre-evaluated based on their potential to solve the problem according to the formulated goals (Haberfellner *et al.*, 2012).

Social system's solution search

This part of the Supply Chain Process Innovation grid refers to designing and managing the technology pre-adoption process to reach the formulated goals of the social system. It, therefore, refers to both the social system while adopting the innovation and the resulting social system. Solution search for the social system involves identifying and analyzing relevant levers and options for the pre-adoption design. Subsequently, for each of the levers, a specific configuration that fits the innovation problem's characteristics must be determined during the evaluation and selection phase. The configuration of these levers directly builds upon the problem analysis and the formulated goals described in the earlier sections. Table 5 provides an overview of essential levers that determine technology pre-adoption design. They span the solution space for proceeding and organizing technology pre-adoption in supply chain management. The table is based on the findings of study A, namely the identification and systematization of response variables for technology pre-adoption in supply chains[22].

Table 5: Managerial and organizational levers of technology pre-adoption in supply chains

	Second-order themes	**Range/answer**
Pre-adoption process	Problem identification mechanisms	How are problems identified and prioritized in the organization? Are they actively collected or passively perceived? Are identified problems considered systematically Examples: ongoing roadmap development, regular discussion in team meetings
	Selection activities	What activities are conducted during the technology pre-adoption process? Where is the focus of activities and resources? Examples: market research, testing, requirements definition, cost comparison
	Change	Are early change activities necessary? What activities to enhance the acceptance of the innovation already during the pre-adoption phase are in place? Examples: internal and external marketing, stakeholder involvement, project branding
	Tools and methods	What specific tools and methods are used during the pre-adoption procedure? For which steps can standard methods be used, for which are specialized or customized methods are necessary? Examples: specification sheet, physical testing, workshops, risk management, business cases, user story clustering
	Decision making	What criteria are used for decision-making? Examples: monetary factors, soft factors
Pre-adoption organization	Team and Roles	How is the team performing the pre-adoption process assembled? What are the responsibilities, and who is holding them? Who is accountable for which aspects? What persons or departments are consulted or informed besides the core team members?
	Project size	What is the planned project duration? What budget is available for the pre-adoption and the overall project? How many resources are allocated towards the problem?
	Partners	Are external partners involved during solution search? Examples: R&D partnerships, consulting firms
	Philosophy	What philosophy is followed during the problem-solving process? Examples: Rigid waterfall processes, unstructured intuitive processes, agile process structure
	Time management	How are the activities conducted time-wise? Can activities be carried out in parallel to save time? How much time is allocated to which activities? Examples: balance between scheduled time for requirements engineering and design phase

[22] For detailed information on the individual themes and the method they resulted from consult study A in Appendix A.

Technical system's solution search

This part of the developed method identifies and analyzes potential technological solutions for the given innovation problem. During the analysis phase, the main characteristics of the innovation problem were recorded systematically in the innovation problem canvas. The research of study C found that some of these characteristics often occur in specific combinations in practice. Subsequently, these findings led to the identification of clusters of innovation problems and made it possible to link specific technologies to these types of innovation problems.

Thus, this step involves classifying the specific innovation problem into one of the empirically derived clusters to identify technological solutions with the highest potential to solve the innovation problem.

Table 6 provides an overview of the derived clusters of innovation problems and their main characteristics to facilitate the classification of innovation problems. Moreover, the table provides insights into typically observed use-cases of these innovation problems and introduces technologies that fit the problem type[23].

The matching of the specific innovation problem to more generic types allows for further analysis and quick focusing on a specialized technological area and thus serves as the first part of the solution search (i.e., synthesis of solutions). During the second step of the solution search, these different solutions must be discussed to evaluate their potential for the specific problem. Also, real-world problems often do not easily fit into one of the generic clusters. Thus, different clusters must be observed and assessed for potentially fitting solutions.

[23] A detailed description of the clusters and the methods used to derive them is given in study C in Appendix C.

Table 6: Clusters of innovation problems, main characteristics, and suitable technologies

Cluster	Main characteristics	Typical use-cases	Technologies and technology characteristics
1: Enable inter-organizational flow tasks in open systems.	• Enable new object flows • Create information or verify physical flows • Scope: Dyad or network	• Tracking, tracing, monitoring solutions (e.g., geographical position, temperature, identify, physical characteristics) • Creating information or enabling faster access to information	• Sensor technologies and auto-identification • Distributed ledger technology
2: Enable information storage in and beyond organizations.	• Information flows and information storage • Enabling or reducing the effort as main goals • Intra-organizational, dyad, and network-level	• Aggregate existing information • Allow accessibility or visualization of information (e.g., dashboards, monitoring systems intra-firm or platforms network-wide)	• Cloud computing, software platforms, data centers, distributed ledger technology, smart mobile applications
3: Create and transfer information along supply chains.	• Information flows • Creation and transition of information • Enable, accelerate, or automate information flows in or between organizations • Closed or controlled systems with reduced complexity	• Automation of transition of information flows: automated re-orders between supply chain partners (e.g., digital Kanban) • Acceleration: Better information provision for shop-floor workers • Enable and automate the creation of digital information	• Smart wearables, sensors, machine learning algorithms, distributed ledger platforms
4: Improve output of information handling in organizations.	• Modification of information • Improve the outcome of information modification • Closed or controlled systems on the intra-firm level	• Examples comprise route optimization, maintenance planning, data analysis • More precise solutions to processes that were solvable before	• Machine learning algorithms and corresponding hardware to process large amounts of information
5: Improve the physical dimension in organizations and supply chains.	• Physical flows in organizations or between supply chain partners • Closed or controlled systems • Enable, accelerate or automate the creation, modification, and verification of physical flows	• Creating physical assets as a production process often refers to enabling unique designs, rapid prototyping, or automation • Verifying physical flows as tracing their origin or certifying specific characteristics	• Creation: Additive manufacturing, robotics, intelligent machinery systems • Verification: distributed ledger technology
6: Automate physical storage on the organizational level.	• Physical storage on the intra-firm level • Automation and acceleration of processes	• Aid in picking process for human workers • Automate intra-logistics transport • Automate and optimize warehousing through overarching systems	• Intra-logistics robots • Intelligent warehousing
7: Improve the physical transport in open systems.	• Physical transport • Complex open systems • Dyadic scope • Automate, accelerate or reduce necessary resources	• Physical delivery in complex real-world settings • Reducing human interaction in these processes through partly automation (e.g., vehicle operation or loading) • Accelerate the tasks by using radically new transport opportunities (e.g., drone delivery) • Reducing resources through modern transport concepts (e.g., platooning, sustainable delivery robots)	• Autonomous vehicles comprising different sub-technologies • Autonomous trucks and trains, delivery and loading robots, drones, software, and sensor technology

Harmonization of the social and technical systems' solution search

Synthesized solutions of each sub-system must be examined in an overall socio-technical context after individual pre-evaluation. Thereby, it is crucial to identify conflicts regarding potential social and technical sub-system solutions. Furthermore, potential conflicts must be evaluated for all potential combinations of technical and social system solutions. A practical approach for this harmonization poses the confrontation of essential stakeholders of each sub-system in a structured environment.

7.3.4 Evaluation and selection of a solution for the innovation problem

This part of the Supply Chain Process Innovation Grid is concerned with selecting the best solution from the solution search phase systematically and transparently. The main criteria for the selection stem from the goal formulation phase for each of the sub-systems. Although all necessary information is available in this phase, evaluation and selection poses a critical step. In practice, decisions are often influenced by personal biases (conscious or unconscious), and thus the evaluation and selection should be supported methodologically (Selensky and Hofmann, 2020a). As a result, the selection phase of the Supply Chain Process Innovation Grid determines which technological application should be focused on during a subsequent detailed study for the innovation problem and how this study should be conducted.

Social system's evaluation and selection

During the evaluation and selection phase of the social system, the results from the analysis and the goal formulation for the social system have to be matched with specific configurations of the managerial and organizational levers. So, naturally, it is difficult to provide a best practice for every possible combination of situational factors and goals, especially to empirically validate these combinations.

However, study A revealed some propositions for successful technology pre-adoption in supply chains, linking some of the influencing factors with important response variables[24]. An overview of these propositions is given in Table 7. These propositions provide actionable *if-then explanations* according to contingency research's primary purpose (Willner *et al.*, 2016). Following the interaction approach of fit, implications on

[24] A detailed description of the propositions and the methods used to derive them is given in study A in Appendix A.

performance were identified for selected pairs of contextual variables and corresponding responses (Drazin and Van de Ven, 1985).

Technical system's evaluation and selection

Based on the considerations of the solution search, a specific technological application is determined in this phase for detailed analysis and planning in subsequent projects. There is a wide variety of methods to support evaluation and decision-making systematically. For example, Systems Engineering is often combined with methods such as argument balance for qualitative assessment or utility analysis to quantify different criteria and measure how the solutions fulfill each (Haberfellner *et al.*, 2012). These methods suit the generic setting of technology selection and are not be explained in detail as they are commonly explored and applied in the existing literature (e.g., Breiing and Knosala, 1997).

The Supply Chain Process Innovation Grid proposes the process-technology fit measure as an essential indicator for decisions on technology deployment as a supplement to existing generic evaluation methods. Study C revealed a connection between innovation problem types and technological characteristics. Therefore, during evaluation, it should be assessed how each potential technological application (as identified suitable during solution search) fulfills the primary characteristics required by the innovation problem. Figure 22 illustrates the inter-relationships and provides a structured canvas for the process-technology fit evaluation. Thereby, the individual weightings of the technology characteristics for each cluster are pre-determined on a scale from one to three, based on study C's findings. Scores of specific technological applications from the solution search phase must be added for each technology characteristic to assess the overall fit measure in a specific cluster.

Harmonization of the social and technical systems' evaluation and selection

Similar to the beforementioned harmonization during the solution search phase, solutions of the individual sub-systems must be compared and harmonized after final selection. However, this harmonization is conducted less broadly but with more depth, as potential solutions are fewer.

Table 7: Propositions for successful technology pre-adoption

		Propositions for successful pre-adoption	
		If	**Then**
Pre-adoption process	Pre-adoption tasks and technology markets	Low access cost for technology	Minimize administrative and documentation efforts and focus resources on productive activities (e.g., testing, market research).
		Complex, dynamic, and very granular technology market	Implement long-term market research strategies instead of ad-hoc research.
		Wide use of technology in other industries	Shift pre-adoption focus from open solution searches to transferability analysis to improve speed.
	Pre-adoption tasks and competencies	Low competency level for technology usage	Define and plan training activities early to consider necessary resources during selection and ensure user acceptance through early involvement.
	Change activities and complexity	High complexity (internal and external)	Conduct early implementation of individually targeted change activities (e.g., user demos, user stories, project branding) for each stakeholder group to ensure acceptance and utilization.
	Tools and methods and criticality	High criticality and impact of mistakes	Deploy extensive testing favorably under realistic conditions in addition to laboratory environments to ensure effectiveness and acceptance.
	Decision making and regulations	Regulations restricting the solution space	Adapt the decision-making model and decision criteria in early phases of pre-adoption to avoid increased selection effort.
	Decision making and technology markets	Unavailability of feasible technological solutions	Adapt decision criteria to market conditions, as mismatch can lead to selection delay. Conduct make-or-buy analysis.
	Decision making and strategy	Strategic interference on decision making	Identify potential inference on decision making early or avoid if possible, since it can have negative implications regarding selection speed, effectiveness, unbiased decisions.
Pre-adoption organization	Team and Roles and complexity	High internal complexity	Clearly define roles and prioritize and document goals of different stakeholders to ensure commitment throughout the project.
	Project size and criticality	High criticality regarding the main business activity	Mitigate risk by allocating adequate resources to the pre-adoption effort. Shift the focus of pre-adoption towards failure avoidance and create awareness for this focus.
	Philosophy and regulations	Procedural restrictions of regulations	Do not over-emphasize restrictions and evaluate overall philosophy nonetheless while accounting for restrictions. Harmonize technical regulations with approaches to ensure acceptance (e.g., agile methods even for rigid regulatory approaches).
	Philosophy and technology markets	Flexible price structure or low entry cost in the overall technology market	Utilize benefits of trial-and-error as part of the pre-adoption procedure. Use access to technology for testing to ensure effectiveness, acceptance, and selection speed.
	Philosophy and culture	Traditional and rigid culture of the organization regarding approaches and methods	Integrate agile elements into the overarching procedure resulting in a hybrid philosophy (e.g., waterfall approach regarding main milestones with agile iterations in between milestones).

	Individual weighting in each cluster | application's score						
Technology characteristics	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Data quality	3|	1|	3|	3|	2|	1|	1|
Locatability of data	2|	3|	2|	2|	1|	1|	2|
Authorization to access data	3|	3|	1|	1|	3|	1|	1|
Data compatibility	3|	3|	1|	2|	1|	1|	2|
Training and ease of use	3|	1|	3|	1|	1|	2|	1|
Production timeliness	1|	2|	2|	3|	3|	3|	3|
Systems reliability	3|	2|	1|	1|	3|	3|	3|
Relationship with users	1|	1|	3|	3|	2|	3|	1|
Fit measure: sum of weighting x score	**?**	**?**	**?**	**?**	**?**	**?**	**?**

Figure 22: Template for process-technology fit evaluation

8 Conclusion

Chapter 7 elaborated a practice-oriented method to enable organizations to systematically innovate their processes by achieving process-technology fit. Subsequently, this chapter highlights the theoretical and managerial contributions of the dissertation. Thereby, Section 8.1. reflects the theoretical implications of the thesis, consisting of the contributions of the individual studies and overarching contributions. Subsequently, Section 8.2. illustrates the practical contributions of the thesis and highlights the usefulness of the results in guiding organizations to innovate inter-organizational processes systematically. Lastly, Section 8.3. concludes the thesis by examining the limitations of the research and proposing future research directions.

8.1 Theoretical implications

This research responds to the need for a theoretical understanding of the interplay between technologies and their environment and how supply chain managers approach technology adoption decisions under consideration of this interplay. Therefore, this thesis aims to develop a method to systematically innovate inter-organizational processes in supply chains, explicitly considering the fit between processes and technologies. The thesis identified three research gaps in the context of designing a method that enables process-technology fit. Based on these gaps, the individual studies formulated and answered research questions.

Study A takes a management perspective on the process of technology pre-adoption and thereby answers $RQ1_a$ and $RQ1_b$. It responds to $RQ1_a$ by identifying relevant contextual factors of technology pre-adoption and structuring them based on empirical data. As a result, eight different groups of influencing factors were identified and allocated to the three overarching categories of firm-specific, network-specific, and environmental factors. These findings contribute to theoretical knowledge in technology adoption by questioning the best-practice paradigm and systemizing the problem-space of possible influencing factors.

Similarly, study A identifies and systemizes potential responses in managing technology pre-adoption, thus offering a systematic solution space. This solution space includes ten different themes of responses that are allocated to the two dimensions selection process and selection organization. This system of response variables enhances current literature by providing a holistic and contingent view on technology pre-adoption. Moreover, the research of study A is one of the few in the field to explore the topic empirically.

Lastly, based on the identified influencing factors and responses in pre-adoption management, the polar-case setting allowed to analyze the data for configurations leading to positive or negative outcomes. These configurations provide an answer for $RQ1_b$. The interaction approach from contingency literature fit was used to identify these configurations (Drazin and Van de Ven, 1985). Thus, concrete propositions for successful technology pre-adoption under certain influencing factors are contributed to the existing knowledge.

Study B responds to the shortage of problem-focused research in innovation management and the lack of conceptualization of innovation problems. Thereby, it answers RQ2 and contributes to theory threefold. First, the study contributes to existing knowledge by illuminating the problem space of the task-technology fit model with particular regard to SCM. This thesis formulated the need to expand task-technology fit theory beyond the individual onto the process level and apply it to a supply chain-specific context. Study B enables meeting this need by allowing for specific and rigorous operationalization and measurement of the problem space of inter-organizational supply chain processes. These are necessary to investigate the inter-relationship between problem and solution space in the context of process innovation (i.e., the characteristics of available supply chain technologies). These contributions ultimately aid theorizing on the relationship between innovation problems in supply chain processes and technologies in a formal way to predict the outcomes of technology deployment and improve technology adoption decisions.

Study B also contributes through its scientific utility provided by the developed taxonomy (Corley and Gioia, 2011). This utility lies in enabling researchers to define and classify their unit of analysis when researching the field. The taxonomy thus increases conceptual rigor in future research as it facilitates operationalizing and testing constructs related to innovation problems in supply chains.

Lastly, study B contributes to theory by structuring existing knowledge to conceptualize innovation problems in supply chains, which has not been done in this way so far. Thus, the study provides an in-depth perspective on supply chain processes and innovation problems while existing research views them as black-box constructs. Furthermore, the study breaks the one-size-fits-all paradigm to acknowledge differences in innovation problems' relationships with technologies, performance outcomes, research approaches, and measurement, among others. The taxonomy resulting from study B thus contributes a more fine-grained classification of innovation problems to theory and paves the way for further research in this regard (Fawcett *et al.*, 2014).

Study C links innovation problems to technological applications and their abstract characteristics. Thus, the contributions of this study can be divided into deriving groupings of innovation problems from empirical data and theorizing on the fit between innovation problems and technologies' characteristics, answering $RQ3_a$ and $RQ3_b$. The empirically derived groupings of innovation problems proved meaningful and valuable, thus contributing to theoretical knowledge by providing useful archetypes of innovation problems (Bailey, 1994). Researchers can use these as a foundation for future research or define their unit of analysis more precisely.

Furthermore, study C contributed to theory by linking different types of innovation problems in supply chain processes with technologies that have successfully been deployed to innovate them and especially their characteristics based on the findings of Goodhue and Thompson (1995). Thus, the results pose a first step towards theoretically explaining the performance outcomes of specific technologies in a specific environment in inter-organizational supply chain processes. Understanding this inter-relationship marks elaborating a supply chain-oriented process-technology fit model based on task-technology fit theory.

Existing research has fallen short on providing such a model, especially considering inter-organizational processes, a holistic technological perspective, and theorizing on process level instead of individual or group level. To sum up, study C study contributes to theory by providing an empirically based conceptualization of technology-enabled process innovation in supply chains, which has not been done in this way so far.

In addition to the contributions of the individual studies, this thesis provides an overall theoretical contribution, despite the practical focus of the findings' integration. The thesis contributes to an identified research gap on problem-solving approaches. This gap is concerned with the abstraction levels of existing approaches, being either too generic to be applied easily for specific problems or too specific to be applied to other contexts. First, the overarching findings provide a specific method to enable systematic process innovation by achieving process-technology fit, which has not been done this way so far. Second and more importantly, the overall thesis provides a methodological contribution to theory. Thereby, the overall approach of the thesis, consisting of the individual research studies focusing on detailed aspects together with an overarching study to integrate these findings based on established problem-solving approaches, can serve future research as a blueprint to bridge the gap in abstraction levels mentioned above. Besides solving the specific problem regarding process innovation in supply chains and process-technology fit, the thesis has a broader impact. It enables researchers to apply the same approach for many problems, developing empirically founded and practically useful methods.

8.2 Managerial implications

This research responds to the practical need for approaching radical or disruptive process innovation in supply chains systematically. Thereby, it focuses on how the process innovation must be approached and how it must be designed and, therefore, contributes to practice in different ways. Every study has its individual practical implications, while the overall thesis also provides an overarching practical contribution.

Study A deploys a management perspective on technology pre-adoption in supply chains. It provides supply chain managers with a useful guideline on which factors to analyze and consider by elaborating and systemizing relevant influencing factors and response variables of technology pre-adoption. Additionally, study A provides actionable propositions for specific configurations of influencing factors and responses that have proven successful. Practitioners can use these as a guideline when preparing pre-adoption initiatives. The practical usefulness of study A's findings is illustrated in Section 7.3, where the findings inform the developed Supply Chain Process Innovation Grid during different phases, focusing on the social sub-system.

Study B designed a taxonomy to systematically analyze innovation problems in inter-organizational supply chain processes. From a practical point of view, this study contributes to practice in two ways. First, it provides a common understanding of innovation problems in supply chain processes and makes the construct accessible for supply chain managers. Access and awareness for this construct are critical because practitioners often neglect the problem-side of process innovation. The problem needs to be understood in-depth to innovate the process with a fitting technological solution.

This need for a detailed problem understanding poses the second practical contribution of study B. The taxonomy is a practical tool facilitating systematic definition, comparison, evaluation, and analysis of process innovation problems. The application conducted during the study and the integration of the adapted taxonomy into the analysis phase in the form of an innovation problem canvas (Section 7.3) highlight the applicability to real-world problems and pose a contribution in itself (Corley and Gioia, 2011).

Study C connects innovation problems and technologies. From a practical perspective, the study reduces complexity related to technological applications by simplifying different problems and solutions into seven manageable clusters. These clusters allow for clear communication on the topic, structured analysis of problems, and efficient solutions design. Study C enables supply chain managers to classify their organization's problems, analyze similar problem types, and find fitting technological solutions based on empirical insights. Although detailed analysis is still necessary after this first indication of fit, the findings enable practitioners to focus their resources and attention during technology pre-adoption when facing a specific problem.

At last, the developed method serves as an actionable guideline with specific, empirically founded tools to enable supply chain managers in systematically innovating supply chain processes by achieving process-technology fit. So far, no comparable methods exist that are holistic regarding the social and technical perspective of process innovation on the one hand and very specific and detailed on the other.

8.3 Limitations and future research

This thesis is built on established and carefully selected theories (i.e., TTF, STS, CT) and deployed rigorous methods during its overall research approach (i.e., case study research and content-coding, systematic literature review, quantitative clustering, design science research). However, like every research, it is not without limitations. Therefore, this section critically discusses the thesis regarding its content-related and methodology-related limitations and proposes avenues for future research.

Content-related limitations of this dissertation comprise the general scope of the research setting and the research concentration on pre-adoption as part of the adoption process. The chosen topics of process innovation and technology pre-adoption are very generic and broad. The thesis narrows the focus by placing itself at the interface of process innovation, technology pre-adoption, fit literature, and supply chain management. However, it still considers a holistic perspective, including various technologies and processes. This broad perspective was chosen because the literature review found that holistic approaches are missing in this specific intersection in research and practice. However, pursuing such a broad perspective brings some limitations for the research concerning its depth and accuracy while it enhances its applicability at the same time. The thesis pursued to mitigate the issue of detailed analysis by focusing on specific aspects in each study, thus reaching a level of in-depth understanding for each chosen topic. Nonetheless, this understanding is limited in depth compared to studies with a higher focus regarding technologies and processes (e.g., research on pre-adoption of IoT technologies in warehousing processes). For example, due to the higher-level holistic focus, the thesis did not utilize process mapping to analyze empirical processes on a detailed level.

Another content-related limitation arises from focusing on technology pre-adoption, leaving adoption and post-adoption out of scope. As elaborated earlier in this thesis, the focus on pre-adoption seems highly reasonable because it allows a deeper analysis of the pre-adoption phase, which was found to have a very high impact on adoption success compared to its deployed resources (Selensky and Hofmann, 2020a). On the other hand, the pre-adoption, adoption, and post-adoption phases of technology initiatives are interdependent, and these inter-dependencies need to be accounted for by research spanning multiple phases. The inter-dependencies between the phases were shown during the overarching research phase. Some of the social sub-system's goals during pre-adoption could only be measured during adoption or post-adoption. Although this dissertation acknowledges these inter-dependencies, it cannot account for them in detail due to the focus on pre-adoption.

Methodology-related limitations of this dissertation comprise the data used, the general assumption on process-technology fit in the data, and the evaluation of the resulting method. As elaborated in Section 6.1, the overall research approach of this thesis deploys various empirically-based data sources during the individual studies. Each of these data sources has advantages and disadvantages to consider and aims to draw a comprehensive picture of technology-enabled process innovation in supply chains. Like most qualitative case studies, Study A is limited by the number of cases observed. Especially regarding the proposed interactions of influencing factors and response variables during technology pre-adoption, the exhaustiveness and expressiveness of the findings are limited by the dataset's size. Moreover, study B used indirect empirical data to derive the characteristics and dimensions of innovation problems in supply chain processes. Although the individual papers were filtered consequently during the systematic literature review for relevance, quality, and empirical foundation, this can be seen as a limitation of the data.

Lastly, study C uses secondary data during the clustering and derivation of innovation archetypes. This dataset also poses a limitation of the methodology, as most studies relying on secondary data and deploying quantitative analysis have. The dataset used was assembled using rigorous guidelines and selection procedures. However, there is still some risk regarding biases when categorizing qualitative data. Also, the deployed dataset has to be evaluated regarding representativeness, balance, and size. Although the data was found suitable to answer the given research questions, the limited number of cases and the dominance of some characteristics in the dataset pose methodological limitations to the findings.

Lastly, the assumptions regarding the data for elaborating the process-technology fit model pose a methodological limitation of the thesis. Study C assumed that empirical use-cases collected in the database provide positive examples of a fit between innovation problem and technology characteristics. This assumption causes limitations of the research for two reasons. First, the dataset was created on secondary data, and thus the cases could not be analyzed and assessed as detailed as with primary empirical observations. Thus, there is some risk that the case's source portrayed the use-case and the outcome incorrectly. However, study C applied a rigorous and clearly defined data sampling process regarding the sources and use-cases to mitigate this risk.

Second, the assessment of use-cases regarding their performance impact and thus regarding their fit was done binary. As mentioned above, the secondary data did not provide enough detailed information to measure fit on a fine-grained scale. Therefore, this simplified measurement of fit in the empirical cases limits the research's findings.

Despite these limitations, the research pioneered analyzing and formally describing the inter-relationships between innovation problems and technological characteristics in supply chain processes. Future research should take up the path and enhance this research by deploying more extensive and more accurate datasets and more precise fit measures. More specifically, the following avenues for future research on technology-enabled process innovation and process-technology fit were identified:

- *Qualitative evaluation of the relationship between innovation problem and technology characteristics*: In-depth case studies and expert interviews should be conducted to examine each of the resulting archetypes of innovation problems and their related technological characteristics in detail.
- *Large-scale dataset to replicate the innovation problem clustering and derivation of the process-technology fit inter-relationships*: Future research should consider the limitations raised above by replicating the quantitative approach of study C deploying a larger dataset. Moreover, use-cases in the dataset could be enhanced and verified by additional primary or secondary data to improve the reliability of the findings.
- *Supplementary empirical data on the relationships of influencing factors and response variables during technology pre-adoption*: Future research should deploy more case studies to evaluate and adapt the proposed dimensions of influencing factors and response variables. Moreover, future research should use additional empirical data to complete propositions on the interactions between influencing factors and responses. Finally, the existing propositions could also be tested in future research.

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Appendix

Appendix A[25]. Selensky, S.: Towards a contingency theoretic perspective on technology pre-adoption in supply chain management

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Appendix B[26]. Selensky, S. and Hofmann, E.: The Anatomy of Innovation Problems – Towards a Taxonomy for Supply Chain Processes

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Appendix C[27]. Selensky, S.: Towards a process-technology fit in supply chain management – a theory-driven approach to understanding Industry 4.0

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Appendix A – Study A

Towards a contingency theoretic perspective on technology pre-adoption in supply chain management

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Purpose: Emerging technologies and the concept of Industry 4.0 are on the rise. Thus, available solutions for SCM get more complex and dynamic. Technology adoption is crucial for organizations competitiveness, but resources are limited. Therefore, this paper aims to gain insights into the successful management of technology pre-adoption in SCM.

Design/methodology/approach: In-depth polar case studies of technology pre-adoption initiatives in various industries were collected using an interview-based approach. Subsequently, the paper deploys transcript coding on the data to analyze information within and across the cases. Lastly, utilizing contingency theory, supply chain-specific influencing factors and corresponding management practices were identified.

Findings: The research reveals eight contingency dimensions and corresponding variables that influence the design of successful technology pre-adoption in SCM (e.g., complexity and criticality). Moreover, ten response variables were identified, referring to the pre-adoption process or organization. They systemize possible options when conducting technology pre-adoption initiatives.

Originality: This research is among the first to provide in-depth insights into technology pre-adoption from an organization's perspective considering supply chain-specific contingencies. Also, it introduces a new perspective on technology selection as a management process.

Research implications/limitations: The paper contributes to research by systemizing potential influencing factors and responses of technology pre-adoption through an explorative, empirical study. The paper is limited by its qualitative approach and the number of case studies conducted.

Practical implications: The results provide supply chain managers a guideline for analyzing potential influences on the technology pre-adoption process and propositions how to manage pre-adoption accordingly.

Keywords: technology selection, technology identification, supply chain technologies, interaction form of fit, contingency theory

Introduction

Emerging technologies and the concept of Industry 4.0 are expected to change the way supply chains operate fundamentally (Hofmann *et al.*, 2019). In practice and research, expectations on the benefits of these technologies could not be higher. Optimized planning and predicting events, decentralized data-based decision making, and autonomous transport are only a few examples of new tasks for technologies along the supply chain. Expected benefits are improved flexibility, quick response to changes in the market, and improved quality and productivity, among others (Hamzeh and Xu, 2019). As history shows, technologies play a critical role in an organization's competitive advantage, and thus there is an urge, strategic or operational, for technology adoption in supply chain management (SCM).

Although expectations in technology adoption are high, it is controversial if a higher level of technology deployment always leads to a significant increase in productivity (Autry *et al.*, 2010). Technologies must fit the tasks they are implemented for, as Zigurs and Buckland (1998) state. Moreover, Liu *et al.* (2016) identified that implementation does not lead to the expected benefits if the technology is not accepted and utilized in the organization.

Since technology projects consume high amounts of scarce resources, financially and capability-wise, organizations cannot implement every emerging technology. Especially since technology markets have become more broad and dynamic in recent years (Autry *et al.*, 2010). Therefore, identifying and selecting the right technologies for the organization's problems becomes crucial for SCM and value creation to exploit technological possibilities and stay competitive.

Many examples of information technology projects that have wasted organizations' resources or even endangered their business operations undermine the relevance of technology pre-adoption (Closs *et al.*, 1997b). A recent example is the Adidas Speed factory project, where a high technology site was built in Atlanta, USA. However, after four years, the project was canceled due to organizational problems, leaving a significant gap in Adidas' balance sheet (Pankow, 2019).

Research on technology pre-adoption has a rich tradition in conceptual, design-driven methodologies. Following the best-practice paradigm, models and methods for successful technology selection are built and proposed for specific environments or technologies. However, they strongly focus on characteristics of technologies and decision-making and leave the view on technology pre-adoption as a management process widely unnoticed. We argue that technology pre-adoption, especially in SCM, is a highly dynamic and diverse process and thus hard to model rigidly. Moreover, every decision differs and must be handled with a suitable practice. For example, the scope of the problem or the decision's impact can vary highly, making different approaches to pre-adoption necessary. This paper addresses this research gap by viewing the pre-adoption of technologies in SCM as a diverse management process, influenced by many different factors, and calls for individual design depending on specific problems. This research gap is addressed by the following research questions (RQ):

RQ1: What contingency factors influence the pre-adoption of technologies in SCM?

RQ2: How must the pre-adoption of technologies in SCM be designed to maximize resulting benefits?

In order to answer these questions, contingency theory (CT) is utilized to reflect the perspective of adaptive pre-adoption design under changing circumstances. The structure of the paper is as follows. First, the existing research on the topic and related fields is reviewed critically. Subsequently, the research methodology is described in detail. Then, the findings are described by proposing answers to the research questions above. Finally, the paper concludes with a discussion of the findings, including limitations and further research ideas.

Literature review

This section provides a literature review on research related to technology pre-adoption in SCM. First, it defines supply chain technologies (SCT) for this paper to differentiate the topic from related research fields such as product or production technology research. Secondly, an overview of previous research on technology pre-adoption is given, resulting in research gaps addressed by the paper with the research questions defined above. Lastly, contingency research and its application in SCM, operations, and innovation management research are analyzed. Based on this body of literature, the methods section elaborates a basic framework for CT research on SCT pre-adoption.

Supply chain technologies

Today, there are few terms used as often as *technology*, whether in research, practice, or daily life. Moreover, there are often very different things associated with the term. Thus, this paper elaborates a short definition and conceptualization by decomposing the concepts of technology and supply chain management.

In a broad sense, technologies can be defined as the “practical application of knowledge especially in a particular area” or as a “manner of accomplishing a task using technical processes, methods or knowledge” (per Merriam-Webster dictionary, 2020). This generic definition can be specified for SCM by seeing the *particular area* as supply chain management and interpreting the mentioned *tasks* as supply chain tasks or processes. Consequently, a proper definition of SCM is needed in the context of this paper. In their seminal work on the definition of SCM, Mentzer *et al.* (2001) screen extant literature and distinguish three types of definitions: SCM as a management philosophy, SCM as the implementation of management philosophy, and SCM as a set of management processes. Although all three are equally valuable, the process perspective fits best to define SCT due to its operationalizability. An early definition of SCM from a process perspective is *“the process of managing relationships, information, materials flows across enterprise borders […]”* (Mentzer *et al.*, 2001). A more detailed view of processes of SCM is delivered by the SCOR-Model, which decomposes SCM into the main process building blocks plan, source, make, deliver, return, enable (Eßig *et al.*, 2013). For this research paper, this process perspective is used to define SCM. Autry *et al.* (2010) define SCT as “*the tools and/or techniques that may be implemented in order to effectuate integrated supply chain management within or across organizational boundaries.”* The paper at hand builds upon this definition by specifying integrated SCM as the processes of managing relationships, information, and material flows according to Mentzer *et al.* (2001) and using the SCOR-Model for further specifying these processes. Thus, SCT can be defined as *tools and techniques that may be implemented in order to effectuate integrated management of relationships, information, and material flows along the supply chain across enterprise borders. More specifically, tools and techniques that support plan-, make-, deliver-, return- and enable- processes.*

The notion of the term *technology* can still differ regarding the abstraction level. While in some papers, it is seen as a very abstract basic concept (e.g., Big Data Analytics), in other cases, it assumes concrete tools (e.g., ERP or EDI-Systems) or, in practice, even specific solutions by a particular provider (e.g., SAP Ariba).

Technology pre-adoption in supply chain management

Zhu *et al.* (2006) distinguish three phases when modeling technology adoption as an ideal-typical process: pre-adoption, adoption, and post-adoption. Similarly, Gregory (1995) proposes a technology management framework from a company's perspective composed of five generic steps: identification, selection, acquisition, exploitation, and technology protection. Technology identification and selection can be summarized in the pre-adoption phase by integrating these two widely used frameworks. The paper adopts this understanding of pre-adoption, including identification and selection, and focuses on this phase because managerial problems refer to it especially (Scheiner *et al.*, 2015).

As discussed in the operations and supply chain literature, the problem of technology pre-adoption can be described as identifying and selecting the most beneficial option from a set of alternative technologies (Singh and Sushil, 1990). Moreover, due to the critical importance of new technologies, their pre-adoption plays a crucial role in companies' and supply chains capabilities to compete (Hamzeh and Xu, 2019; Armayor *et al.*, 2011a). Accordingly, there is a rich body of literature on the topic.

First of all, there are some literature reviews on technology pre-adoption. Raafat (2002) provides a comprehensive bibliography on the justification of advanced manufacturing systems, building on an earlier bibliography from Son (1992). Although they cover a significant amount of relevant work on the topic, they do not discuss or reflect the content of the identified research. Moreover, published in 2002, they miss out on important new pre-adoption and justification models regarding industry 4.0 technologies. A more recent review of the literature was conducted by Hamzeh and Xu (2019). Focusing on manufacturing, they review pre-adoption methods and applications in research from 1990 to 2017. Their findings show that selection criteria can be divided into tangible, intangible, quantitative, and qualitative categories. Another classification of selection criteria can be made by dividing economic, technical, environmental, and social criteria.

Regarding the main selection methods, Hamzeh and Xu (2019) identify analytical hierarchy processes (AHP), data envelopment analysis (DEA), fuzzy logic, financial analysis, mathematical programming, and hybrid methods as main categories in recent research. While they identify a notable growth in research on technology selection, especially in product design and production processes, they recognize that technology selection in SCM is still emerging (Hamzeh and Xu, 2019). As the literature review shows, most of the research on the topic originates in operations research. Many papers analyze the selection of production technologies (e.g., Naik and Chakravarty, 1992; Almannai *et al.*, 2008), while there is an extensive research stream focusing on advanced manufacturing technologies and their selection for producing companies (e.g., Kuei *et al.*, 1994; Thomassen *et al.*, 2014). Although there are very relevant papers on SCT adoption (e.g., Liu *et al.*, 2016; Zhang and Dhaliwal, 2009; Autry *et al.*, 2010), literature on the selection of SCT specifically is still scarce. Relevant work in this area refers to specific sub-questions or superordinate topics, including supply network design (e.g., Elhedhli and Gzara, 2008). Another review of existing selection techniques for technologies, focusing on automation technology, was conducted by Alfnes *et al.* (2016). The authors compare relevant selection techniques by assessing the project phases they support and using a defined set of evaluation criteria (e.g., ease of performance, covering of necessary areas, type of approach). They suggest that the choice of the selection method should depend on the type of acquisition process of the company, technology strategy, competencies, and supplier relations (Alfnes *et al.*, 2016).

Besides analyzing existing literature reviews, this paper conducts a semi-structured literature review to evaluate the state of research on technology pre-adoption in supply chain management in more detail. Thereby, the databases Web of Science and Scopus were searched for the keywords (technolog*) AND (select*) AND (supply chain). The review was limited to papers published in 2011 or later because the reviewed work should address modern technologies considering the possibilities associated with Industry 4.0. Moreover, only peer-reviewed research was taken into scope. For each of the search strings, relevant synonyms (e.g., "evaluation," "assessment") were also searched and tested so that the final search strings were elaborated iteratively. The most relevant and most cited papers were retrieved from each database for a detailed review. For the most relevant papers, a backward search was conducted. Finally, twelve papers on technology pre-adoption considering supply chain management aspects were considered substantial such as the three literature reviews on the topic mentioned earlier. Inclusion criteria for relevant papers were that the pre-adoption of technologies must be the focus of the study and that the type of technologies in focus must comply with the definition of SCT given above. For the analysis of the retrieved papers, they were categorized by their theoretical contribution and their research methods deployed, and their primary domain focus (Table 1).

A-Table 1: Relevant research related to technology pre-adoption in SCM

Author (Year)	**Research method**	**Theoretical contribution**	**Domain/technology focus**
Essakly et al. (2019)	Conceptual (demonstration by case study)	Framework of performance metrics	Industry 4.0 solutions in SME
Thomassen et al. (2014)	Empirical (based on literature review and action research)	Strategic approach for decision support	Automation technology
Farooq and O'Brien (2012)	Conceptual	Structured analytical approach (i.e., framework with six steps)	Intra-organizational perspective
Collins and Williams (2014)	Conceptual	Three-stage selection tool (framework and process)	Tested in product development / smart materials
Farooq and O'Brien (2015)	Empirical (based on action research)	Technology selection framework	Manufacturing
Chuu (2014)	Conceptual (illustration by example)	Technology evaluation process	RFID technology
Hassan et al. (2015)	Empirical (based on literature review and Delphi study)	- Influencing factors and subgroups on the selection of auto-ID technology - multi-stage selection framework	Auto-identification in warehouse management
Büyüközkan et al. (2012)	Conceptual (illustration by case study)	Evaluation criteria and decision-making methodology (Two-stage, AHP & TOPSIS)	Mobile logistics tools
Xia et al. (2017)	Conceptual	Modified strategic balanced scorecard	Features of sustainability of technologies in SC
Khatri and Srivastava (2016)	Conceptual	Multi-criteria decision-making model (AHP)	Sustainable supply chains
Armayor et al. (2011)	Conceptual	Decision support model (based on fuzzy logic)	Information systems integration in supply chains (i.e., technologies for integrating other information systems)
Ribeiro et al. (2016)	Conceptual (demonstration by case study)	Multi-dimensional evaluation approach	Sustainable manufacturing technologies

The analysis of the selected papers shows that most of the previous work on technology pre-adoption with consideration for SCM has a conceptual nature. While some papers are solely relying on literature for modeling a new selection approach, tool, or framework (Farooq and O'Brien, 2012; Collins and Williams, 2014; Xia *et al.*, 2017; Khatri and Srivastava, 2016; Armayor *et al.*, 2011a), others illustrate a developed selection model or process by application on a case study (Essakly *et al.*, 2019; Büyüközkan *et al.*, 2012; Ribeiro *et al.*, 2016). Only a small proportion of the identified papers is empirical. Thomassen *et al.* (2014) propose an approach for decision support to select automation technologies based on action research methodology. Also, Farooq and O'Brien (2015) facilitate an empirical action research approach to develop a technology selection framework from a supply chain perspective. Hassan *et al.* (2015) provide an explorative study, analyzing factors affecting selection decision of auto-identification technology in warehouse management before contributing an own multi-stage selection framework. In addition to their literature review, the authors conducted a delphi study to investigate key decision-making factors and their importance.

Concluding the analysis of the current state of literature related to SCT selection, the following gaps can be summarized:

- There is a rich body of research on technology pre-adoption in operations, especially in production technology and automation or specific technologies (e.g., auto-identification). However, research on SCT selection considering inter-organizational aspects from a holistic perspective (i.e., considering various SCT and including selection process management) is still scarce.
- Regarding their contribution, extant research almost solely focuses on developing new selection frameworks, decision models, or process approaches. Following the best-practice paradigm, these approaches provide concrete solutions while leaving little space for adjustment to company-specific conditions. Also, this mainly design-driven research provides little insight into the primary constructs of technology pre-adoption and successful selection practices in companies.
- Regarding the methods deployed, extant research on technology selection has a strong history in being conceptual and design-driven, while empirical, qualitative, and explorative research methods are very scarce in this domain.

Contingency theory and innovation management

Contingency theory (CT) originates in explaining the structure of organizations under particular circumstances. Based on this origin, CT was transferred to several research disciplines to show dependencies on specific circumstances and how a case should be managed (Gassmann *et al.*, 2016a). Thus, CT also applies to decision-making, innovation management, and technology pre-adoption. In this section, the main influencing dependencies of innovation are elaborated, and a typical contingency framework and contingency factors from the domain of operations management are identified from the literature.

Tidd (2001) suggests that innovation management depends on the type and degree of innovation. The innovation type differs in process and product or service innovation, and the innovation degree reaches from incremental over radical to disruptive innovations. For this paper, this classification will narrow down the object of interest by including radical and disruptive innovations in the scope. They are specified further into technologically enabled innovations applied in one of the main SCM processes, following the SCT definition elaborated above. Product innovations are out of the scope of the conducted research. Technology pre-adoption is an innovation process with specific characteristics that make its management unique. Innovation processes can be characterized by complexity, uncertainty, diversity, and interdependence. Moreover, an innovations' success depends on (1) the match between the people involved and their roles, (2) the choice of the innovation process, and (3) the organization of the process itself (Boer and During, 2001).

A typical contingency framework consists of three types of variables: (1) contingency variables, (2) response variables, and (3) performance variables. While contingency variables account for the situational characteristics, they are not or only hard to manipulate by organizations. Response variables, in contrast, are the organization's reactions to the contextual variables. At last, performance variables are the dependent measures to evaluate the success of the response variables, thus measuring the fit between context and response.

When conducting CT research, different forms of fit between context and response have to be considered (Doty *et al.*, 1993). One prominent distinction was made by Drazin and Van de Ven (1985), based on different configurations of the relationship between contextual, response, and performance variables: selection, interaction, and system approach. While the selection approach views fit as an underlying condition, it is not measured whether a particular configuration affects performance. The interaction approach defines fit as the interaction of pairs of context-response variables, which affect performance in a certain way. Thus, those approaches examine how single context variables affect single response variables (Sousa and Voss, 2008). In contrast, the system approach addresses many contingencies and many responses to affect performance.

Contingency research has gained popularity in recent years, especially in operations management. For a long time in research and practice, the search for best practices was the dominant logic following the best practice paradigm (Voss, 1995). This paradigm was supported by research showing the link between operational performance and the adoption of best practices. Examples of these practices in operations are lean manufacturing or total quality management (Sousa and Voss, 2008). Nonetheless, there is much discussion today about whether there is one best practice in operations management that fits various situations of companies.

Furthermore, the best practice paradigm is undermined by the criticism, that the studies supporting it firstly have a bias in case sampling, consisting of large, multinational high-tech companies, and secondly that the survey-based method lacks in examining contextual richness of the different cases (Sousa and Voss, 2008). Based on this criticism, many researchers followed contingency-based approaches to examine operations-related management activities. Table 2 shows an overview of contingency factors and contextual variables of previous research on operations management practices. For the paper at hand, the notion of contingency factors and contextual variables of Sousa and Voss (2008) is adopted, thus contingency factors being general groupings and contextual variables being specific, measurable indicators inside those groupings.

A-Table 2: Contingency factors and contextual variables in OM literature (adapted from Sousa and Voss (2008))

Contingency factor	**Contextual variables**
National context and culture	Strat. time orientation, parent country, country of location, Hofstede's dimensions of national culture, level of country development
Firm size	No. of employees
Strategic context	Product customization, production volume, rate of new product introduction, item variety, production run sizes, type of production processes, level of international competition, scope of operations, environmental uncertainty, firm orientation (customer vs. operations), situational uncertainty, policy for satisfying customer demand, type of production process, logistical complexity, product value, volume, complexity, degree of emphasis on complexity, platform strategy
Others	Var. organizational variables, industry, nature of work and technology, values of participants, specificity, technological complexity, essentiality, fragility, variability, unionization, plant age, industry equipment

Methods

This paper applied a multiple interview-based case study approach given the scarceness of in-depth research on the management of SCT pre-adoption and its diverse occurrence in practice. Furthermore, this approach is in line with the recommendations made for case study literature since the main research questions of this study ask *what are the key variables?* and *how SCT pre-adoption in companies must be designed to account for those variables?* (Meredith, 1998). Moreover, case study research enables the documentation of managerial practices and understanding the nature and complexity of studied phenomena and thus, increases the depth of research which is the goal of this study (Yin, 2018; Voss *et al.*, 2002). Moreover, the chosen approach fits the explorative nature of the study.

Within the case study-based approach, contingency theory was used as a theoretical basis for the investigation. More precisely, its constructs were deployed to classify the resulting themes from the data into CT categories: contingency factors, selection practices, and performance measures. Thus, the study aims for abductive reasoning on the inductive cases.

The unit of observation and the unit of analysis was defined as follows for the case study analysis. The overall proceedings of a specific organization's SCT pre-adoption were considered the unit of observation. These proceedings include (1) the project's initial situation containing the triggers for action, (2) the related activities that followed the initial situation, and (3) observing and evaluating measures of the SCT after implementation to indicate performance impacts (e.g., effectiveness or acceptance). For this timely restricted section, information regarding the organization itself, the supply chain setting, and the environment were considered. The unit of analysis focuses on management practices during SCT pre-adoption. These practices include activities and decisions that are influenceable by the organization. Thus, the unit of analysis is narrowed down to the response variables compared to the unit of observation while implementing an SCT after the selection is excluded from the analysis.

Sampling

Following case sampling guidelines provided by Eisenhardt (1989b) and considering the research goals, a set of sampling criteria was created to guide data collection.

- *Criterion 1 - Variety in firm-specific factors:* Selected cases should reflect a broad spectrum of possible organization types. To ensure this variety, cases were selected from organizations of different sizes, cultures, and industries.
- *Criterion 2 - Interorganizational context:* Since the study focuses on SCM technology selection, one important characteristic is the scope, which should go beyond one organization, adding more complexity and reflecting supply network configurations. Thus, cases were only selected for the sample if two or more organizations were involved in the SCT project directly or at least affected indirectly.
- *Criterion 3 - Technological innovations:* For cases to qualify for the sample, they should deal with the selection of innovative technological solutions in SCM. The technologies have to reflect the notion of the industry 4.0 concept, as they contribute to "*The vision of a highly integrated [supply chain], in which individual goods are produced sustainably in a mass-production manner to fulfill customer demands in a global competition*" (Winkelhaus and Grosse, 2019a). Technologically the cases must address one of the core technologies, Internet of Things (IoT), cyber-physical-systems (CPS), big data analytics, cloud computing, or

mobile-based systems, which were found to be the main building-blocks of industry 4.0 in literature by Winkelhaus and Grosse (2019a). To focus this definition further, technologies sampled need to have a physical and a digital component directly or at least have one of those components with an interface connecting to the other.

- *Criterion 4 - SCM Process innovations:* Lastly, this study focuses on cases in which SCM processes should be changed or optimized using technological tools. Referring to the definition of SCT and process innovations given before, this means that product innovations (e.g., improvements of product characteristics or services) and production technology innovations (e.g., CNC milling) are excluded from the sampling scope since they do not effectuate integrated SCM directly.

Data collection

The heart of the collected data is semi-structured interviews, which were enriched with other data sources such as informal follow-up interviews and archival data. The interviews were conducted in three different companies, examining five cases. The informants held positions in technological or SC-related fields and were experts in their field. Also, in every case, the main responsible person conducting the SCT pre-adoption process was included, but also other involved informants to avoid biases.

For data collection, the researchers developed a semi-structured interview instrument. The researchers followed a data collection protocol for every case using this instrument. One week before the interview, the informants were sent a short questionnaire asking about some general information about each case. The interviews began with a short presentation, including the definition of SCT and their roles in SCM. Subsequently, milestones of technology adoption, according to Liu *et al.* (2016), were shown, comprising the steps impulse, reaction, SCT selection, implementation, and usage. The researchers highlighted the focus of the study as the SCT pre-adoption process by defining the unit of analysis for the informants. Next, archetypes of technology projects were presented to motivate the focus on SCT pre-adoption, and the goals of the research project were made clear. Before starting the interactive part of the interview, the informants were shown an overview of the different sections and interview questions on a high level.

The deployed interview instrument consisted of eight sections, covering the unit of observation from initial situation to usage and efficiency measures. The detailed questions on the instrument were not shown to the informants. Instead, open questions were asked for each section so that the informant could explain the proceedings freely. In addition, the interviewers asked questions to guide the explanations if relevant information was missing. The instrument contained 55 questions answered explicitly or implicitly (interview instrument available upon request). The interviews lasted approximately two hours per case. Parallel to the audio interview, the researchers visually elaborated the resulting case on brown paper with the interview partners.

Data analysis

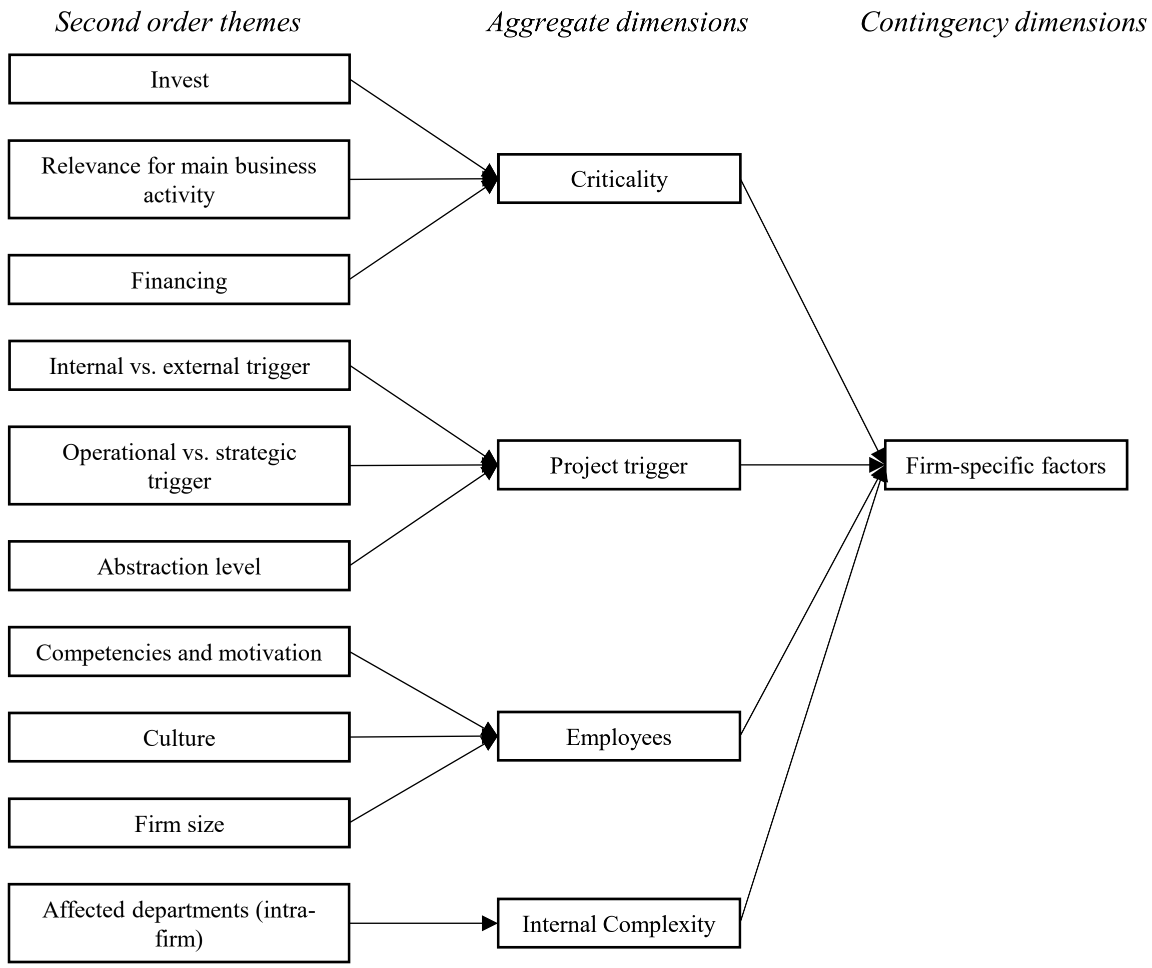
After the data collection described above was finalized, data were available as audio records from the interviews, transcripts from interviews, visual documentation, personal notes, questionnaire data from informants, and archival data on organizations and technologies. As suggested by Gioia *et al.* (2013), data coding was used to ensure rigor during the analysis. The coding followed the four steps: (1) microanalysis of data, (2) grouping into open codes, (3) consolidation of codes, and (4) searching for patterns. During microanalysis, codes for occurring categories in each case are defined without grouping them. The resulting number of categories can be high but gives a very accurate representation of the information given. In the second step, the data set of first-order codes is searched for similarities and differences among the many categories, resulting in a set of more abstract second-order themes (Gioia *et al.*, 2013).

Results

The results section is structured as follows. First, it presents the findings exploring specific contingency factors and contextual variables. Thereby, the results of the data analysis explained in the method section can be summarized in coding trees. Second, the resulting coding tree explains the response variables' findings. These groupings offer a structure to SCT pre-adoption's problem and solution space and thus answer RQ1. Lastly, propositions are drawn from combinations of contingencies and responses, with either positive or negative influence on performance, proposing answers to RQ2.

Contingency variables

Following the first stated research question from the introduction, the researchers analyzed the cases to seek and structure influencing factors on SCT pre-adoption. For every case, information about what has influenced activities performed and decisions made during SCT selection was coded according to Gioia *et al.* (2013). First-order themes were abstracted to second-order themes and then grouped into higher dimensions before being allocated to the overarching groups of CT. An overview of the resulting structure, including eight dimensions of contingency variables on SCT pre-adoption, is displayed in figures 1 to 3. The first-order themes influencing SCT pre-adoption in the observed cases were summarized and generalized into second-order themes shown on the left side of the figures and lastly aggregated into eight dimensions of contingency factors of SCT pre-adoption. In the following, the resulting firm-specific, network-specific, and environmental contingency factors will be explained.



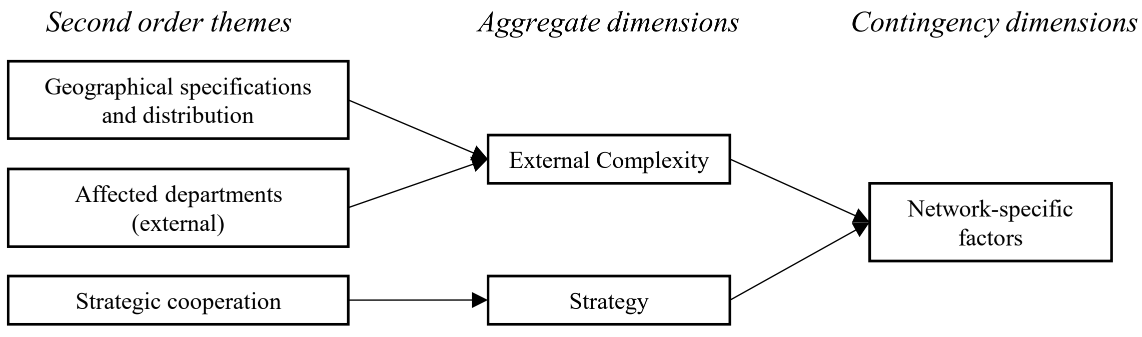
A-Figure 1: Firm-specific contingency factors of SCT pre-adoption

Firm-specific, endogenous factors are often the central part of contingency-based research (Kajüter and Kulmala, 2005). Especially for SCT pre-adoption, a subset of firm-specific influencing contingency factors could be identified: *criticality*, *project trigger*, *employees*, and *complexity*. The *criticality* of a technology-related initiative or problem was identified as an essential factor, as the case studies showed that for highly critical SCT initiatives, a very different approach in activities and organization proved successful. This difference especially relates to pre-adoption effort and project size. From the cases, three contextual variables as measures for criticality could be identified. The investment and the source of the investment pose financial measures, whereas the initiative's relevance for the firm's primary business activity relates to a rather strategic form of criticality.

The aggregated dimension of the *project trigger* explains how an organization takes notice of a need for action and in what form it encounters the problem, thus relating to the identification as part of technology pre-adoption. The data showed that identification processes and organization varied a lot, depending on the abstraction level of the problem. For example, the pre-adoption approach will differ if there is only a very abstract notion compared to the existence of a very concrete idea for a project. Moreover, SCT pre-adoption varies depending on whether a project is triggered externally or internally and triggered operationally or strategically.

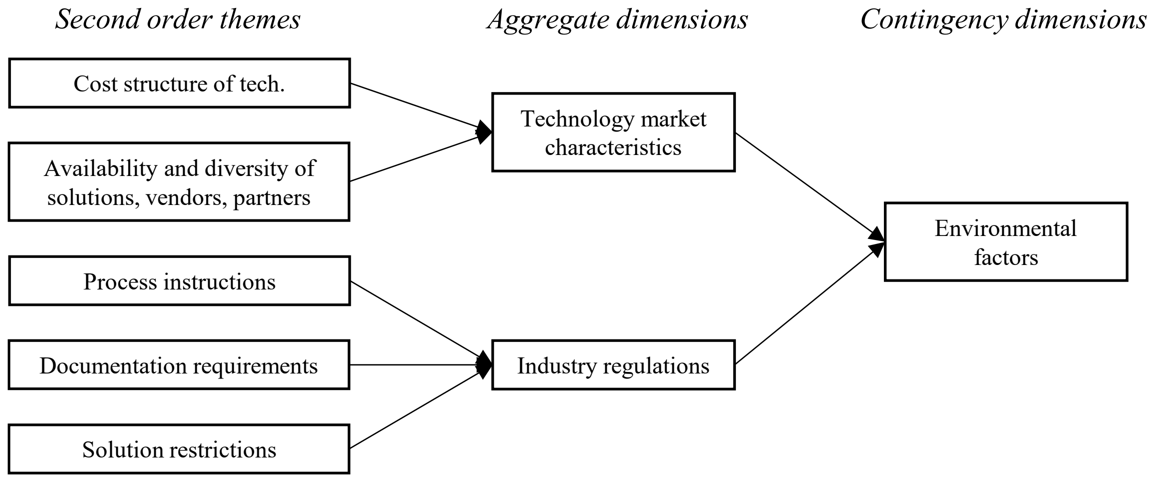
The *employee dimension* aggregates human factors of firm-specific situations. As the data showed, successful pre-adoption depends on who is involved and how they usually approach problems. The data revealed employee competencies and motivation, culture, and firm size as important contextual variables for this contingency factor.

Finally, *complexity* plays a critical role in approaching SCT pre-adoption. Complexity can be divided into a firm-specific complexity that accounts for internal organizational, dependencies, and external complexity, accounting for other involved stakeholders and the environment. As specific contextual variables for firm-specific complexity, intra-firm affected departments and intra-firm geographical distribution were identified.



A-Figure 2: Network-specific contingency factors of SCT pre-adoption

Network-specific factors describe all influencing factors, which are neither firm-specific nor environmental. Especially in SCM, this differentiation accounts for specific situations in supplier-buyer-relationships, such as differences in size and trust among network partners (Kajüter and Kulmala, 2005). The case analysis revealed that the network-specific situation plays a crucial role also for SCT pre-adoption, as projects are inter-organizational and network partners have to be involved in the process to a certain degree. This involvement can vary from intensive collaboration to information sharing. The amount and type of interaction with external departments in the network were aggregated to the *complexity* dimension. In addition, a *strategic* dimension was identified accounting for long-time strategic cooperation among network partners influencing SCT selection.

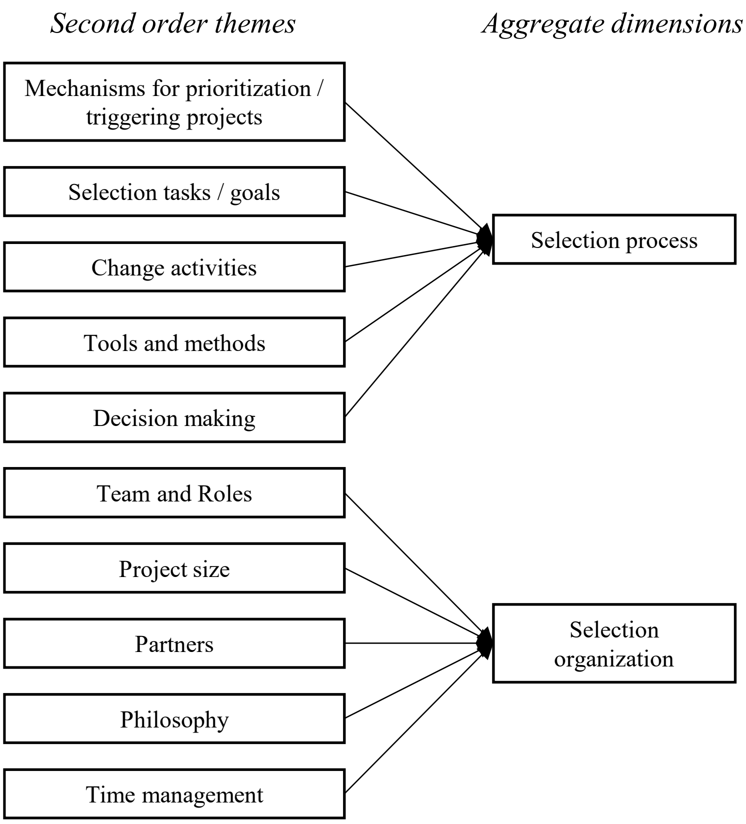


A-Figure 3: Environmental contingency factors of SCT pre-adoption

Lastly, **environmental** factors play an essential role in SCT selection. The study showed that selection approaches and their success vary depending on characteristics of the technology market and industry regulations. As *technology markets* can be highly different regarding the problem and technology maturity, approaches for finding appropriate solutions also differ. Moreover, the cost structure of the technology market influences SCT pre-adoption, making either trial-and-error approaches suitable or calling for detailed and cost-intensive ex-ante analysis. Finally, as suspected, *regulations have* a highly restrictive impact on the pre-adoption processes. These restrictions materialize by excluding specific solutions a priori or prescribing certain process models and documentation guidelines.

Response variables

Response variables describe possible actions an organization or decision-makers can take to manage a situation. It is the sum of all factors an organization can influence (Sousa and Voss, 2008). When analyzing the cases, these possibilities to manage a given situation defined by the contingency factors and corresponding contextual variables were examined. Similar to the contingency factors, a coding tree illustrating and systemizing the response variables is presented in figure 4. The data analysis derived possible influenceable responses regarding SCT pre-adoption and divided them into pre-adoption process and organization. These two dimensions span the solution space of SCT pre-adoption.



A-Figure 4: Response variables of SCT pre-adoption

The **selection process** refers to all activities performed, including methods and tools. Five second-order themes of the selection process could be identified as sub-groups from the first-order themes. The *mechanism for triggering projects* is timely located before the SCT pre-adoption phase and is an essential part of the identification phase. The cases showed that these mechanisms are crucial for later pre-adoption activities and thus included. Other essential factors are the *task* fulfilled during pre-adoption, *change activities*, *tools and methods* used, and *decision making*.

In contrast to the process, the **pre-adoption organization** refers to how the SCT pre-adoption is set up regarding organizational topics like staffing, budget, and overall approach. More precisely, the research identified five second-order themes as sub-groups from the coded data. *Team composition* and role distribution are big levers to pre-adoption success. Another vital decision is the *project size*, defining the time period, budget size, and overall resource allocation. Additionally, decisions on *partners* during pre-adoption and the *overall approach* (e.g., differentiating between agile or waterfall philosophy) are essential to consider setting up the pre-adoption organization. Lastly, the *time management* theme describes the alignment of several activities in context and their management, for example, parallelizing different activities where possible.

Propositions for successful SCT per-adoption

The first part of the results section presented a systematization of influencing factors and a solution space for potential managerial responses for SCT pre-adoption. Subsequently, this second part identifies concrete propositions for the design of SCT pre-adoption based on the collected data. Consistent with CT research, these propositions are designed as *if-then explanations* to guide management under specific circumstances (Willner *et al.*, 2016). The formulation of the proposition is coherent with the *interaction* form of fit elaborated in the literature review on CT research. The interaction form of fit identifies pairs of influencing variables and responses that impact performance.

First, the identified contingencies and responses were allocated in a matrix to elaborate these propositions. Then, the data was revised again, searching for each combination of codes and analyzing the impact on performance. Thereby, the authors evaluated if a specific if-then relationship poses a success or dis-success factor. The identified relationships are explained shortly by naming each affected response variable and the implications certain contingencies have on it, accompanied by the affected performance variables. It is noteworthy that the identified interactions are based solely on the data from the cases, and due to their limited number, they do not claim exhaustiveness.

As elaborated earlier, the *selection process* consists of four dimensions: selection tasks, change activities, tools and methods, and decision making. It was found that the tasks conducted for SCT pre-adoption and the goals followed by them differ and are highly dependent on technology market characteristics and the competencies of a firm. For example, access costs to technology as part of its technology market highly influence pre-adoption tasks. If the costs are relatively low, administrative efforts like documentation can be kept minimum. This way, resources can be focused on productive activities like testing to reduce pre-adoption effort, as observed in Case 1.

On the other hand, long-term market research becomes critical during pre-adoption if the technology market is complex, dynamic, and not easily manageable (e.g., because there are many small and unknown vendors instead). Under these circumstances, ad-hoc research hinders selection speed and cannot ensure finding the best solutions, thus endangering effectiveness, as Case 2 showed. Lastly, market analysis beyond the own industry poses a critical activity. For example, if a specific technology is widely used in other industries already, selection activities shift from unbiased solution search to transferability analysis, thus improving pre-adoption speed, acceptance, and effectiveness of the solution (Case 3).

Employee training poses an important response variable when it comes to the relations of selection tasks and competencies of the firm. If the necessary competencies for the usage of the SCT do not exist, training should be defined and planned early during pre-adoption. First, because necessary measures and expenses must influence the pre-adoption process to ensure effectiveness, and second to ensure acceptance and utilization of the SCT, as shown in Case 1.

Moreover, the data revealed that the complexity of a problem influences the change activities during pre-adoption. For example, if there is a high number of internal or external stakeholders involved (i.e., high organizational complexity), early and individually targeted change activities are necessary to ensure acceptance and utilization by each stakeholder group. Case 5 revealed this correlation, where change activities have proven successful early in the pre-adoption process, using demos, user stories, and project branding, among others.

The data also showed the criticality of the problem influencing tools and methods used during SCT pre-adoption. If failure or wrong decisions would lead to far-reaching negative consequences, extensive testing activities are crucial for the pre-adoption process. Testing thereby involves laboratory and real-environment experiments with real users, depending on SCT type. Thereby, organizations ensure effectiveness and acceptance of the solutions, like cases 2 and 5 showed.

Regulations, technology market characteristics, and strategic aspects influence decision-making during SCT pre-adoption. If regulations restrict possible solutions, decision-making models need to be adapted accordingly. This refers to specific decision criteria, for example. This adaption needs to be elaborated early during the process since it can increase pre-adoption effort, as Case 4 revealed. If the technology market does not provide satisfactory offerings regarding amount or quality, decision-makers must adapt criteria according to the circumstances. A mismatch between criteria and market situation can result in selection delays or project terminations. Case 2 indicated that performing make or buy analysis becomes highly important in this case and can highly impact the pre-adoption process. Lastly, Case 5 showed that strategic interference in decision-making negatively affects pre-adoption speed and effectiveness since it hinders unbiased decisions, compromises prior work, and calls for reorganization.

The *selection organization* consists of teams and roles, project size, partners, and philosophy. The data revealed that the complexity of a problem influences how a team for SCT pre-adoption should be built up. If a problem affects many internal stakeholders and departments with several interests in the topic, roles must be defined clearly, and goals must have clear priorities, including documentation. Case 4 revealed that expected effects and commitment are missed during late project stages if priorities are not communicated and documented.

If a problem is critical to the main business activity of the organization, the size of the project regarding budget and time should be allocated adequately. By increasing the pre-adoption effort, the risk of wrong decisions can be mitigated. Therefore, time and financial resources should be invested appropriately during early phases during pre-adoption and focus on the assurance of effectiveness and acceptance. Firms must be aware of this internal priority shift in the pre-adoption effort towards failure avoidance and be willing to pay its price (Case 2). Regarding project size, the data showed that if a project is embedded in an overarching organization-wide initiative, this usually leads to higher priority and available budget. However, it can also lead to competition between projects in a firm's portfolio or cannibalization of projects (Case 4).

Strategic partnerships play an essential role for firms in SCM. If strategic partnerships exist with possible solution providers, those need to be considered early on during SCT selection because late consideration can hinder selection speed and success due to ad hoc decisions (Case 5). There are several philosophies on how an SCT pre-adoption is set up. The case studies show that regulations, technology markets, and the firm culture influence the choice of the underlying philosophy of the overall approach. If regulations restrict possible procedural approaches, the overall philosophy should still be evaluated and decided actively considering the other contingencies to ensure acceptance. Regulations often refer to technical quality assurance, while acceptance and change fall behind. Planned approaches and regulatory duties should be harmonized. Agile aspects should be accounted for, also in very rigid regulatory processes, as it can lead to additional effort during selection when changes occur, as Case 3 revealed.

If the price structure on the technology market allows for it, the benefits of an iterative trial-and-error procedure can be taken advantage of so that SCT access becomes part of the testing. Changing the solution later thereby holds minimal risk. This way, effectiveness and acceptance can be ensured, and pre-adoption speed is improved due to fast decision making. On the other hand, rigid planning is necessary if the market implies high entry costs and financial obligations (e.g., long-term subscriptions) (Case 1, Case 2). Moreover, the organization's culture and size influence the pre-adoption process structure and rigidness. For example, suppose agile and alternative processes need to be applied, although the firm's culture does not provide it. In that case, these agile elements should be integrated into the overarching process, thus building a hybrid philosophy (e.g., waterfall regarding milestones, iterative between milestones) (Case 5).

Contributions and limitations

This research contributes to theoretic knowledge in three main ways. First, it takes a management perspective on the process of technology pre-adoption and thereby answers RQ1 and RQ2. It responds to RQ1 by identifying relevant contextual factors of technology pre-adoption and structuring them based on empirical data. As a result, eight different groups of influencing factors were identified and allocated to the three overarching categories of firm-specific, network-specific, and environmental factors. These findings contribute to theoretical knowledge in technology adoption by questioning the best-practice paradigm and systemizing the problem-space of possible influencing factors.

Second, this paper identifies and systemizes potential responses in managing technology pre-adoption, thus offering a systematic solution space. This solution space includes ten different themes of responses that are allocated to the two dimensions selection process and selection organization. This system of response variables enhances current literature by providing a holistic and contingent view on technology pre-adoption. Moreover, this research is one of the few in the field to explore technology pre-adoption empirically.

Lastly, based on the identified influencing factors and responses in pre-adoption management, the polar-case setting allowed to analyze the data for configurations leading to positive or negative outcomes. These configurations provide an answer for RQ2. The interaction approach from contingency literature fit was used to identify these configurations (Drazin and Van de Ven, 1985). Thus, concrete propositions for successful technology pre-adoption under certain influencing factors are contributed to the existing knowledge.

Besides the theoretical contributions, this paper also contributes to practice. The research deploys a management perspective on technology pre-adoption in supply chains. Thereby, it provides supply chain managers with a useful guideline on which factors to analyze and consider by elaborating and systemizing relevant influencing factors and response variables of technology pre-adoption. Additionally, findings provide actionable propositions for specific configurations of influencing factors and responses that have proven successful. Practitioners can use these as a guideline when preparing pre-adoption initiatives.

As most research, the conducted research has some limitations and thus holds potential for further investigations. The resulting contingency and response variables offer a framework to allocate a firm's situation and navigate and decide on possible options. As with most qualitative research, case study research is limited by the number of cases observed. Thus, further research should evaluate and enlarge the proposed dimensions. This proposition for future research especially applies to the propositions for specific interactions made. These provide tendencies, but the small data set limits their exhaustiveness and expressiveness.

Moreover, following the suggested sampling criteria, further research should enrich the matrix of interactions with data from other cases. For example, action research-based cases where the researchers influence the progression and have the opportunity to test specific hypotheses could enlarege the data set. Lastly, the interaction form of fit was used to elaborate the propositions on SCT pre-adoption in this paper. Since many researchers in the CT field argue that an accurate understanding of context-response relationships calls for the system approach, further research could deploy this approach with a more extensive data set.

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Appendix B – Study B

The Anatomy of Innovation Problems – Towards a Taxonomy for Supply Chain Processes

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Purpose: Supply chain managers face constant pressure to innovate their processes to stay competitive in volatile and uncertain business environments. Technologies are often in focus to solve these issues. To theorize the interplay of processes and technologies, a proper understanding and conceptualization of the underlying innovation problems in supply chain processes are necessary.

Design/methodology/approach: We follow a rigorous taxonomy development framework outlined by Nickerson *et al.* (2013). It is divided into four phases: systematic literature review, iterative taxonomy development, taxonomy evaluation using expert interviews, taxonomy application.

Findings: Our resulting taxonomy allows supply chain managers and researchers to classify innovation problems in supply chain processes based on three major categories (i.e., process specifications, context specifications, innovation specifications), seven dimensions, and 26 characteristics.

Originality: While existing research focuses on technologies and their application in supply chains, this research focuses on innovation problems. Thereby, this paper is among the first to conceptualize innovation problems holistically. As a result, it lays the foundation for theorizing the fit between technology deployment and innovation problems to improve technology adoption decisions ultimately.

Research implications: The resulting taxonomy contributes to task-technology fit theory as it operationalizes its problem space. Also, it enhances research by integrating existing knowledge and providing a novel, fine-grained classification of innovation problems. Thus, the taxonomy allows for differentiation between various types of innovation problems in future research, as researchers can define and classify their units of analysis more precisely.

Practical implications: The research provides a shared understanding and awareness for innovation problems in practice while existing approaches often focus on solutions or technologies. Also, the taxonomy can be used as a practical tool for decomposing and classifying real-world cases for further analysis and solution search.

Keywords: innovation problem, technology, process innovation, taxonomy, systematic literature review, Industry 4.0, Task-technology fit theory

Introduction

The environments of supply chains are more volatile, uncertain, complex, and ambiguous (VUCA) than ever. To face the challenges of this new “VUCA”-world, supply chain managers need to improve agility, resilience, and risk management of their supply chains while maintaining a high level of cost efficiency (Bennett and Lemoine, 2014; Dohale *et al.*, 2021; Fischer-Pressler *et al.*, 2020). In addition, increasing expectations regarding service, individuality, customization, granularization of orders, and delivery concepts amplify competition between companies and whole supply chains (Marinagi *et al.*, 2014). Thus, supply chain managers face significant pressure to constantly improve their processes using emerging technological advances, often summarized as Industry 4.0 (Kamble *et al.*, 2018; Alicke *et al.*, 2016).

However, organizations struggle to harness the potential of emerging technology to innovate their supply chain processes (Geissbauer *et al.*, 2020). One reason for this poses the complexity of supply chain processes themselves regarding their management and innovation. They reach beyond company borders and thus are characterized by many different stakeholders with different interests. They also simultaneously involve multiple supply chain flows such as information, material, and financial flows, which must be accounted for during process innovation (Vom Brocke and Rosemann, 2014). Thus, supply chain managers already face problems when correctly grasping the issue at hand, even before thinking about suitable solutions.

Additionally, the complexity of technology, dynamic changes of technology markets, and uncertainty about functionality and interoperability of systems lead to uncertainty among decision-makers to identify and select fitting solutions for their supply chain processes (Autry *et al.*, 2010; Winkelhaus and Grosse, 2019b). Supply chain managers lack systematic and theory-driven approaches to analyze their processes, define the innovation problem at hand, and facilitate Industry 4.0 technologies for innovation (Closs *et al.*, 1997a; Essakly *et al.*, 2019; Hamzeh and Xu, 2019).

In recent years, much research investigated the interplay of supply chain processes and emerging technologies from different perspectives. Many studies focus on explaining and predicting the contributions of supply chain innovation, undermining its importance for competitiveness and performance (e.g., Narasimhan and Narayanan, 2013; Chiou *et al.*, 2011; Falcone *et al.*, 2019). Although existing research provides insights on challenges regarding the adoption of Industry 4.0 technologies (e.g., Ghadge *et al.*, 2020), they rarely provide theoretical contributions regarding process innovation design and implementation (Wong and Ngai, 2019). In this context, researchers call for the classification and operationalization of the construct of process innovation in supply chains (Wong and Ngai, 2019; Arlbjørn *et al.*, 2011), for theory-driven approaches to understanding emerging technologies in SCM, and for theories that explain how managers can approach the potential of particular technologies (Bourlakis *et al.*, 2020).

We identified the literature on fit to have great potential to address these needs and improve the quality of technology adoption decisions to innovate supply chain processes. The concept of fit and related theories hold the potential of anticipating the performance impacts of possible technology deployment. In this regard, especially the task-technology fit theory (TTF), as suggested by Goodhue and Thompson (1995) in their article, is highly valuable because it provides the primary constructs for theoretically analyzing technology deployment and insights into the relationships between these constructs. However, literature has not discussed TTF on tasks or processes that incorporate integrated supply chain flows on the process level.

Although there is much interesting and valuable research on technology adoption in supply chains, we theorize that successful technology adoption calls for problem-pull instead of technology-push. Thus, in our view, research calls for a proper understanding of the underlying problems in supply chain processes before they can be innovated enabled by technology. A supply chain-oriented TTF model can fill this gap.

To get one step closer to deriving a TTF model for supply chain processes, we suggest that a detailed understanding of the problem space (i.e., the innovation problem to be solved by technology) is necessary. Therefore, we propose developing a taxonomy that supports supply chain managers and researchers in defining, comparing, evaluating, and analyzing the underlying innovation problems of technology-enabled process innovation. Furthermore, a novel classification using relevant characteristics of the innovation problems will allow for theoretical understanding and classification and provide the first step towards theorizing between innovation problems and technology deployment. Hence, this paper focuses on the following research question:

RQ: *What are the constituting dimensions and characteristics that define innovation problems in supply chain processes?*

To achieve this goal, we develop a taxonomy of innovation problems in supply chain processes for facilitating technological innovation. We follow a rigorous taxonomy development framework outlined by Nickerson *et al.* (2013), divided into four phases. First, we conduct a systematic literature review resulting in 127 recent and relevant, empirically grounded publications on technological innovation in supply chains. Second, we derive a taxonomy with seven dimensions and 26 characteristics, based on this literature and informed by expert discussions. Third, we evaluate and refine our taxonomy in interviews with researchers and practitioners regarding content and structure. Lastly, we apply the taxonomy to a real-world example to illustrate its usefulness and applicability.

The remainder of this paper is structured as follows. The following section presents the theoretical background on process innovation in supply chains and literature on task-technology fit before the method is described in detail. Subsequently, the resulting taxonomy is explained, and its application is illustrated. Lastly, we discuss the results regarding their contributions and derive implications for future research.

Literature review

Process innovation in supply chains

Business processes produce a specific output of value to the customer (Cooper *et al.*, 1997). The *activities* or *tasks* performed in a process characterize units of work that take different kinds of input and create an output of value. A process may be divided into different sub-processes (Aguilar-Saven, 2004; Davenport, 1993; Rummler and Ramias, 2010a; Weske, 2007). Moreover, process innovation can be defined as "*the implementation of new or improved techniques, methods, and procedures*" (Wagner and Bode, 2014 p. 66). For this paper, we will focus on improving techniques, methods, or procedures that originate in the deployment of modern technology, similar to Scannell *et al.* (2000). In contrast to product, service, or business model innovation, process innovation thus strongly emphasizes *how* a company delivers value to its customers instead of *what* kind of value (Boer and During, 2001).

Much discussion and research were undertaken about the interplay of process innovation and technology deployment. Performing a traditional unchanged process with new technology will not necessarily lead to process innovation and thus also fail to lead to relevant performance improvements. The critical discussion about IT usage in white-collar jobs in the USA in the nineties has shown this issue illustratively. For this reason, we will view technology as an enabler of fundamental process changes and thus innovation, as Davenport proposes in his early seminal work (Davenport, 1993). Hence, a process innovation for this paper consists of a process change (i.e., re-design of the process), which is enabled by technology.

Recent technological advances allow the integration of physical and digital supply chains, often summarized as Industry 4.0. These advances pose radical new possibilities to innovate processes (Hamzeh and Xu, 2019). The expected benefits of technology-enabled process innovation in supply chains are manifold. Among others, cost- and revenue-based improvements can be achieved, as new technologies support companies in tackling challenges. These challenges include increasing customer expectations and individualization, sustainability requirements, and volatile and uncertain surroundings (Bennett and Lemoine, 2014; Winkelhaus and Grosse, 2019b; Alicke *et al.*, 2016). However, these technologies also pose problems for companies and decision-makers regarding their selection and implementation into existing supply chain processes. Especially knowledge during the pre-adoption phase and insights on how to analyze existing processes to identify matching technological solutions is still scarce (Wang *et al.*, 2019; Wong and Ngai, 2019).

In the context of this study, we will define *innovation problems* as the companies' recognition of a need or opportunity to innovate. Thus, the innovation problem comprises relevant information of the initial process, including its context and the desired outcomes. Furthermore, it states the basis for the following problem-solving activities: idea generation, information collection, analysis, and evaluation (Boer and During, 2001).

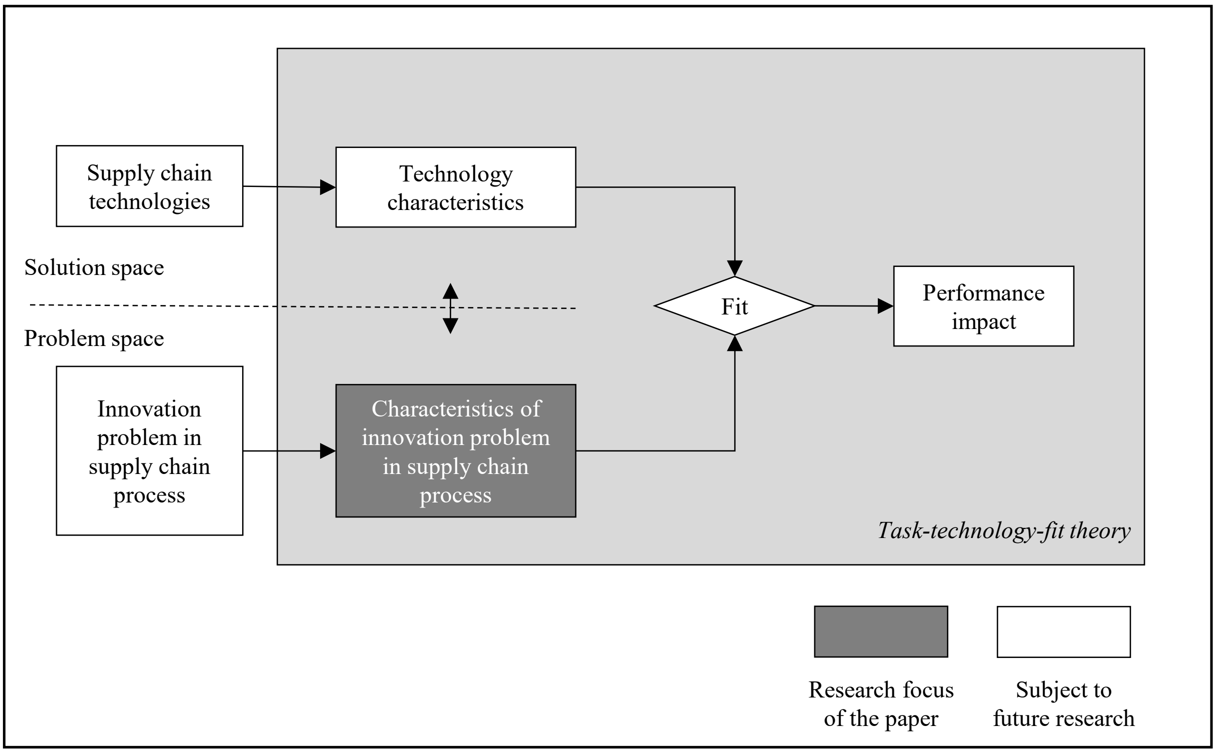
The relevance and the potential of process innovation in supply chains are widely acknowledged in the literature. However, few studies investigate process innovation in supply chains in-depth and explore its content and the conceptual foundations (Arlbjørn *et al.*, 2011). Previous research mainly focuses on explaining and predicting the contributions of supply chain innovation but rarely focuses on theoretical contributions to design and action (Wong and Ngai, 2019). Therefore, a coherent classification is necessary to enhance conceptual understanding and operationalize supply chain process innovation (Wong and Ngai, 2019; Arlbjørn *et al.*, 2011). We propose a taxonomy that facilitates systematic analysis of innovation problems in supply chain processes and thus enables their innovation using Industry 4.0 technologies to address this issue.

Theoretical perspective on processes and technology deployment

The concept of fit is widely used in research to describe the inter-relationships of different constructs and resulting outcomes (e.g., contingency theory, information processing theory). Regarding the fit between technologies and the tasks they are used for, task-technology fit theory (TTF) poses a structured model. It allows ex-ante and ex-post evaluation of technology deployment in a specific context.

In its original form, TTF formally describes the relationship between capabilities of information systems (IS), requirements of user tasks, and individual user performance. It states that the higher the degree of fit between IS capabilities and task requirements, the higher the performance impact of the system deployment (Goodhue and Thompson, 1995). Different variations of the TTF model exist, applying TTF to different contexts or describing slightly altered relationships between the constructs. For example, soon after its first publication Dishaw and Strong (1999) proposed integrating the TTF model with the technology acceptance model (TAM), another highly used model in IS literature. Fuller and Dennis (2009) extend the findings on technology and team performance by a time dimension, showing that a better fit regarding technology and task plays a more significant role in short time frames. Over more extended periods, teams innovate and adapt so that performance also increases for poorly fitted technologies. Applications of TTF in research refer to different types of IS and industries. For example, Junglas *et al.* (2008) apply TTF to mobile locatable information systems using a laboratory experiment. Additional to traditional TTF models, they could show that differences between under-, over-, and ideal fit had implications on task performance. Ratna *et al.* (2018) deploy the TTF model to the context of hotel reservation information systems. They examine the effect of task and technology characteristics on the compatibility of technology and task and the utilization of the information system. Fu *et al.* (2019) apply TTF to enterprise social media usage in organizations based on different task environments. Huscroft *et al.* (2013) are the only ones we identified applying the TTF model to logistics or SCM processes. Their survey-based study examines how the deployment of fitting information technology can support reverse logistics processes by using processing effectiveness and cost-effectiveness as dependent variables to measure performance.

To sum up, achievements in TTF research can be divided into the extension of the model itself and the embedding in IS literature, and the application in different practical contexts. However, the model has not been applied to tasks or processes beyond the individual level, especially not in a supply chain-oriented context. To fill this gap, we suggest an adjusted TTF model based on Goodhue and Thompson (1995) but with specific considerations for supply chain processes, as illustrated in *B-Figure*.



B-Figure 1: Adjusted TTF model for supply chain processes

The framework comprises four main elements: characteristics of supply chain innovation problems, characteristics of supply chain technologies, fit, and the supply chain performance impact. This study aims to contribute to theory and practice by providing a detailed understanding of the problem space, i.e., the characteristics of the innovation problem in supply chain processes. Many recent studies focus on emerging technologies and where and how they can be applied in supply chains (Bourlakis *et al.*, 2020). Although the results of that research are interesting and valuable, we suggest that successful technology adoption in supply chains calls for problem-pull instead of technology-push. Thus, in our view, research calls for a proper understanding of the underlying problems in supply chain processes before they can be innovated enabled by technology.

However, to our knowledge, existing literature fails to provide a generally applicable classification scheme for the in-depth analysis of supply chain innovation problems considering potential technology deployment. Instead, supply chain innovation or processes are usually researched from a higher-level perspective, viewing process innovation as a black-box construct. Furthermore, in existing studies, process innovation is represented by specific measures indicating inter-relationships with other measures, but seldomly it is investigated in-depth. As a result, a problem-oriented classification of process innovations in supply chains, independent of specific solutions and thus technologies, is still missing.

Methods

The previous section illustrated the need to define and classify innovation problems in supply chains, especially from a technology deployment-oriented perspective. To the best of our knowledge, existing SCM and innovation management literature fall short in this specific regard. Taxonomies have proven helpful for systematically classifying objects of interest in many research disciplines (Nickerson *et al.*, 2013). Classifications, in general, provide value to researchers and practitioners as they structure novel and complex domains. They are instrumental in new and emerging research fields, such as deploying emerging technology to innovate supply chain processes. Classifications make different elements of a phenomenon visible and display their relationships transparently and coherently and indicate their respective theoretical basis (Bailey, 1994). Hence, they create value beyond prescribing phenomena. Classifications also serve as input for advancing theoretical knowledge, as in our case, to study the functions and mechanisms of innovation problems in supply chain processes and their interplay with technology (Doty and Glick, 1994). We follow a rigorous taxonomy development process in four distinct phases as outlined in *B-Table* that we will explain in the following.

B-Table 1: Overview of the sequential research phases

	Phase 1: Database creation using a systematic literature review	Phase 2: Taxonomy development	Phase 3: Taxonomy evaluation	Phase 4: Taxonomy application
Steps	Identify relevant literature as the basis for the taxonomy and collect it in a database. Definition of search strings and databases, screen and select relevant papers, code and analyze papers.	Define meta-characteristic. Iterate taxonomy development procedure until ending conditions are met.	Evaluate taxonomy with experts based on defined criteria.	Apply the resulting taxonomy to analyze a real-world case example of technology-enabled process innovation in SCM.
Methods	Systematic literature review (SLR) approach by vom Brocke et al. (2015). Qualitative coding.	Taxonomy development following (Nickerson et al. 2013)	Expert evaluation (Szopinski et al. 2019)	Taxonomy application.
Sources	Recent literature on technology-enabled innovation in SCM.	Database with characteristics and mechanisms of process innovations in SCM. Expert workshops.	Semi-structured interviews with domain and classification experts.	Resulting taxonomy of process innovation in SCM. Case of technology-enabled process innovation. Data gathered through workshops.
Results	Database (i.e., Excel-Spreadsheet) with 127 papers and according characteristics and underlying mechanisms.	Taxonomy of process innovation in SCM.	Evaluated and revised taxonomy of process innovation in SCM.	Insights on applicability and usefulness of the developed taxonomy.

Phase 1: Database creation using a systematic literature review

The first step aims to identify relevant literature as the basis for the taxonomy and collect it in a database. For this purpose, we conducted a systematic literature review (SLR) following vom Brocke *et al.* (2015). SLRs can be defined by their scope regarding the four dimensions of process, source, coverage, and techniques (vom Brocke *et al.*, 2015). To establish the basis for the taxonomy development and conceptualization, we used a sequential process to search bibliographic databases and publications for relevant seminal works, using keyword search as a technique. We will explain each of the methodological steps shortly to ensure transparency and reproducibility.

Search string

The search aimed to collect knowledge on technology-enabled process innovation in supply chain processes, to derive distinctive characteristics from literature. Hence, the search string was composed of three elements. The first accounts for the technological component, the second for the supply chain-specific aspect, and the last ensured that only empirically derived knowledge is considered:

("technolog" OR "industry 4.0" OR "IT" OR "information systems" OR "disruptive" OR "transforma* "digit*") AND ("supply chain" OR "interorganizational" OR "inter-organizational" OR "sourcing" OR "procurement" OR "purchasing" OR "logistic*" OR "warehouse" OR "transport*" OR"cyber-physical" OR "ecosystem" OR "network" OR "smart" OR "production" OR "manufacturing") AND ("empiric*")*

Databases

We aimed to identify representative literature samples of different research perspectives on technology-enabled supply chain innovation. Hence, we conducted a database search including multiple journals and conference proceedings, which are relevant due to their timeliness in this dynamic topic. The search comprised four databases: EBSCO, Emerald Insight, ScienceDirect, and Web of Science.

Papers

The search resulted in 1'100 unique publications, which we screened using the title and the abstract. Subsequently, we analyzed the resulting 127 papers in more detail. We included only papers where technology deployment in an SCM context was the main topic and where process innovation was focused. Finally, we applied a coding procedure, extracting the literature's defining characteristics and underlying mechanisms of technology-enabled process innovation and underlying innovation problems.

Analysis of papers

We coded the papers from the SLR to highlight relevant information for this study. Based on the codings, patterns and groups of codes were identified and summarized into higher-level topics. Subsequently, resulting topics were evaluated for potential utilization in the taxonomy as dimensions or characteristics.

Phase 2: Taxonomy development

This study aims to develop a taxonomy of innovation problems in supply chain processes to systematically represent existing knowledge and integrate findings on technological innovations into a holistic conceptual model. We follow Nickerson *et al.* (2013) to develop the taxonomy because it provides a rigorous step-by-step approach widely acknowledged, especially in IS literature. Furthermore, due to its structured process and precise definition of ending conditions, the approach ensures the completeness of dimensions and characteristics of objects.

Firstly, we defined a meta-characteristic that reflects the overall purpose of the taxonomy. In general, we aim to theoretically investigate the role of technology deployment in innovation problems in supply chain processes, especially from a perspective that evaluates technology deployment ex-ante. Thus, the characteristics of innovation problems in supply chain processes under consideration of technology deployment are chosen as meta-characteristic of the taxonomy. More precisely, this primarily refers to developing an artifact that enables supply chain managers to design, compare, evaluate, and analyze innovation solutions and problems in supply chain processes by a novel classification to facilitate support or fulfillment by technological systems. We seek to theorize on distinctive technical and situational features of supply chain processes that describe the business need and objective relevant to innovation.

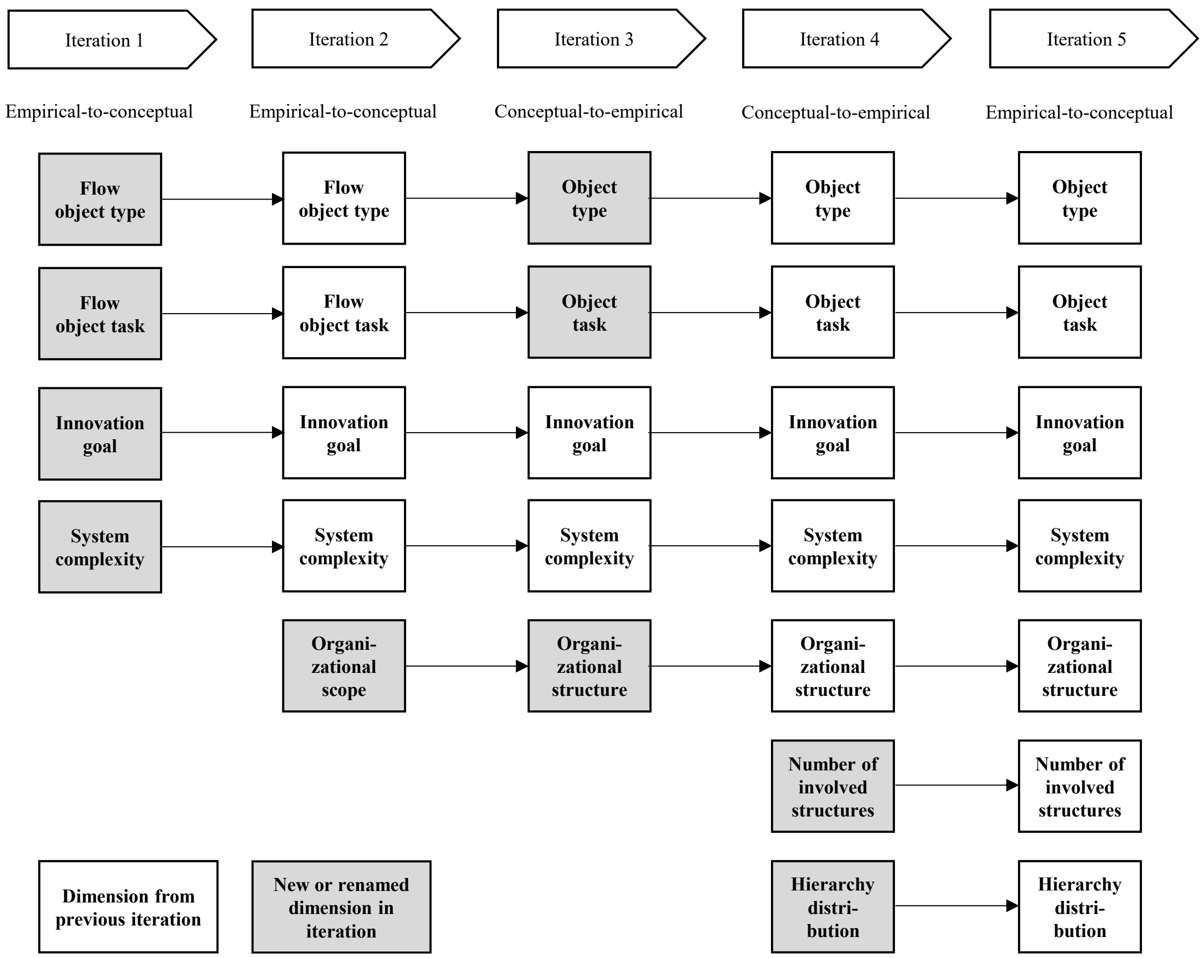
As proposed by Nickerson *et al.* (2013), the following ending conditions were defined:

a) No new dimension or characteristic has been added in the last iteration.
b) Every dimension and every characteristic in its dimension are unique and do not repeat.
c) Every known example of technology-enabled process innovation in supply chains can be classified in the taxonomy.

The iterative taxonomy building process differentiates between empirical-to-conceptual and conceptual-to-empirical approaches for defining dimensions and characteristics. These approaches can be interchanged during the subsequent iterations. A conceptual-to-empirical approach involves examining empirical cases regarding how they fit with the initial conceptualization, while an empirical-to-conceptual approach involves starting with empirical data clusters before conceptualizing the nature of each cluster

(Nickerson *et al.*, 2013). It is worth mentioning that in our case, the empirical-to-conceptual approach also involved conceptualizing the findings from the literature review, as they pose empirically grounded examples found in the literature.

B-Figure 2 shows the development of the taxonomy over different iterations. Although the number of dimensions was comparably low during the process, many iterations were also necessary to define each dimension's characteristics based on the literature. Expert workshops additionally informed the taxonomy development process. For this, the documentation of six interactive workshops from September 2018 to August 2020 on the characteristics of technologies and innovation with industry experts was evaluated in retrospect. The group consisted of senior-level researchers and senior-level practitioners from the SCM field.



B-Figure 2: Iterations of the taxonomy development process

Phase 3: Taxonomy evaluation

The development process is stopped once the earlier defined ending conditions are met (Nickerson *et al.*, 2013). Subsequently, the quality of the resulting taxonomy needs to be tested against five main criteria: conciseness, robustness, comprehensibility, extendibility, and explanatory power (Nickerson *et al.*, 2013). Accordingly, we followed the evaluation suggestions of Szopinski *et al.* (2019) and conducted semi-structured interviews to ensure the taxonomy meets the relevant criteria. In total, we conducted five interviews with either domain experts from the SCM field in practice, SCM in research, or classification and taxonomy development in general. In each interview, 14 open questions addressing the five main evaluation criteria were asked. We sent the taxonomy to the interviewees before the interviews that were conducted via online video conference. The results of the evaluation were as follows:

- Explanatory value: This measure describes the ability of the taxonomy to explain and illustrate the relationships between different elements and characteristics transparently. Also, it refers to whether the taxonomy is understandable to users (Nickerson *et al.*, 2013). All experts think the taxonomy is understandable and provides explanatory value. However, one expert mentioned that some of the dimensions are relatively high-level and thus not as easily understandable. All experts suggested small changes regarding naming specific dimensions (i.e., innovation goal, object task, object type) and characteristics regarding the innovation goal, which we followed.

- Conciseness: This measure describes the ability of the taxonomy to describe the phenomenon sufficiently without overwhelming the user. Thus, it refers to the number and meaningfulness of dimensions and characteristics (Bailey, 1994). Overall, the interviewed experts did not perceive the taxonomy as overwhelming. However, one interview partner suggested minor changes to increase the meaningfulness of the "innovation specification" dimension, which we followed.

- Robustness: This measure describes how to differentiate sufficiently without overlap between categories or classified elements (Bailey, 1994). Overall, the experts think the taxonomy has a high discriminatory value to differentiate. One expert suggested adding another dimension related to the hierarchy between supply chain partners to improve robustness, which we did. Another interviewed expert pointed out some overlaps regarding the topics of organizational scope and organizational structure, which we fixed.

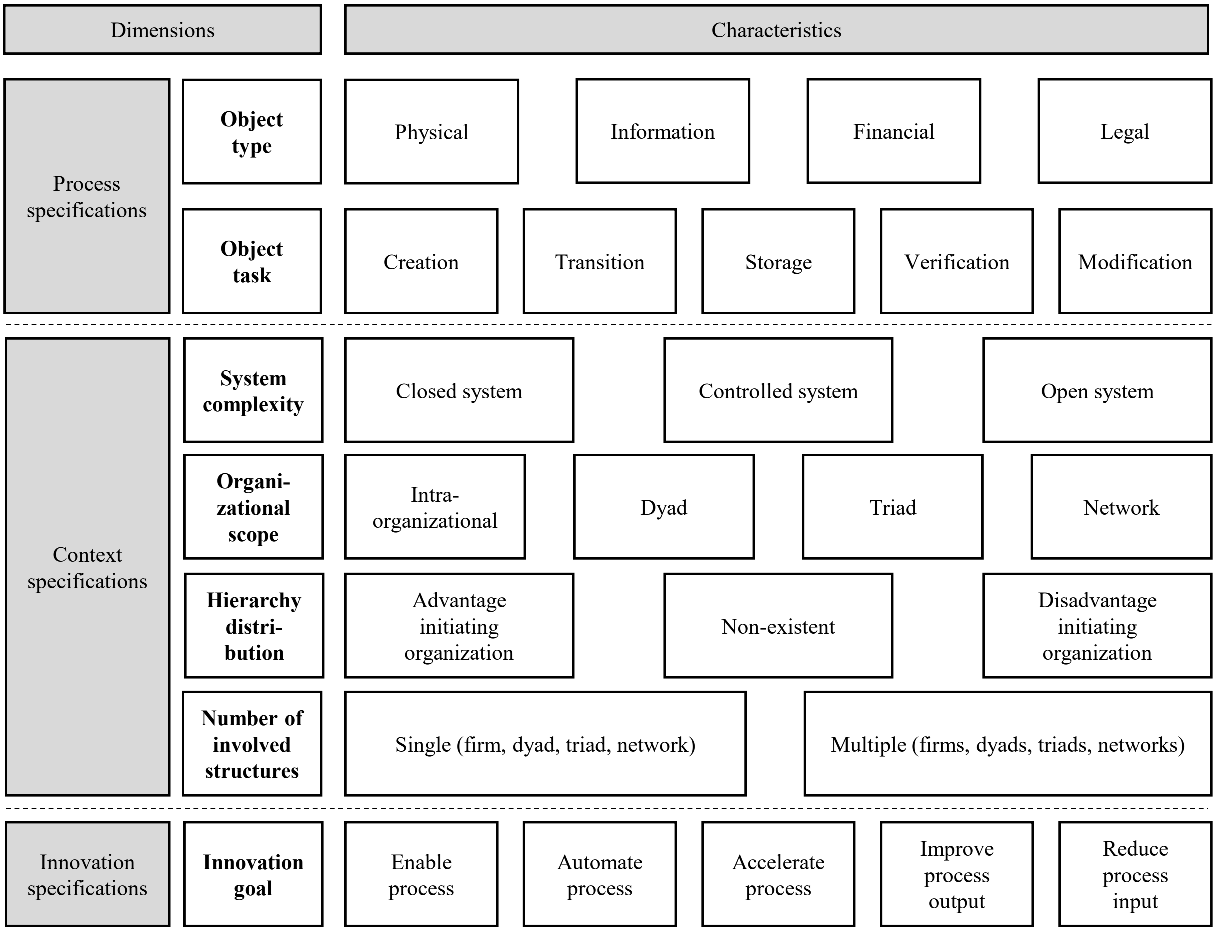
- Comprehensiveness: This measure refers to the coverage of objects of interest and thus the completeness of the taxonomy (Bailey, 1994). Overall, the experts perceived the taxonomy as complete, even after test-classifying current problems from their daily work. We discussed the addition of a financial dimension with one expert, which we discarded as it refers to the solution space rather than the innovation problem in particular.
- Extendibility: This measure refers to whether the taxonomy is static and can be adapted to changing environments and its ability to serve over extended periods (Bailey, 1994). We explicitly designed the taxonomy to be independent of specific technological or supply chain-related trends. The expert interviews confirmed that we reached this goal. Nonetheless, the experts did not identify explicit restrictions regarding the extendibility of the taxonomy if it should be necessary for the future.

Phase 4: Taxonomy application

As the last step of the taxonomy development approach, we highlight the usefulness and applicability of the resulting taxonomy. We do this by applying it to a real-world case example. Although classifying a case based on secondary data would be feasible, we chose an example from a project conducted in 2019 that we know in-depth. Information about the case was gathered through four interactive workshops in which we analyzed the given process in detail, identified problems and goals, and elaborated on possible solutions. The documentary of these workshops provides an excellent opportunity to apply and evaluate the designed taxonomy ex-post using a simplified version of the actual case.

Taxonomy of Innovation Problems in Supply Chain Processes

The following section presents the consolidated version of the taxonomy after conducting five iterations and revisions from the expert interviews. All design elements were identified as suitable for conceptualizing innovation problems in supply chain processes in the context of potential technology deployment. We derived and elaborated the design elements from the reviewed literature and discussions with experts. Each dimension and its characteristics will be described in the following. The complete taxonomy is shown in *B-Figure 3*.



B-Figure 3: Taxonomy of innovation problems in supply chain processes

Overall, the design elements can be divided into process specifications, context specifications, and innovation specifications. The process specifications refer to the process itself and are characterized by the object type and the object task of the process. The context specifications refer to the surrounding context in which the process is performed and consist of the system complexity, organizational scope, hierarchy distribution, and the number of involved structures. Lastly, the innovation specifications refer to the process's aspired change and are defined by the innovation goal.

Process specifications

The process specifications refer to the specific characteristics of a supply chain process, describing how input is processed into an output to create value. We identified nine generic characteristics to define the value creation of a process, divided into the two dimensions of object type and object task.

The **object type** dimension refers to *what* type of supply chain flow is affected by the process. In line with seminal SCM literature and the reviewed papers, these can be divided into physical objects, information, financial assets, and legal assets (Jespersen and Skjott-Larsen, 2005; Bowersox *et al.*, 1999; Mentzer *et al.*, 2001). A supply chain process may affect several objects simultaneously (e.g., physical transport and real-time tracking of transport conditions), especially as emerging technology integrates supply chain flows. However, a process can be broken down into lower-level activities or tasks which can be assigned to a single object affected, and the combination of these allows to model integrated supply chain processes.

- *Physical objects* refer to all kinds of tangible assets in the supply chain, especially materials and products. For example, the reviewed papers' innovations comprise material flows enabled by robotics or cyber-physical systems (Winkelhaus and Grosse, 2019b; Morenza-Cinos *et al.*, 2019).
- *Information* refers to intangible assets in explicit or implicit forms like data or knowledge. Examples in the reviewed papers revealed information flows enabled by the internet of things (IoT) or storage of and access to information enabled by cloud computing (Garrido-Hidalgo *et al.*, 2019b; Barenji *et al.*, 2019).
- *Financial assets* refer to non-material, monetary assets. They primarily include cash or cash equivalents and deposits, interests, or other forms of financial assets. Examples in the context of process innovation in supply chains include simple money transfers like invoice payment or more complex processing of financial contracts enabled by distributed ledger technology (DLT) (Roeck *et al.*, 2020; van Hoek, 2019a).
- *Legal assets* are not very common in SCM research until now. However, the expert discussions revealed that this aspect is essential, as it is often neglected. Examples of legal assets in a supply chain context are intellectual properties, specific rights or ownership, and usage rights of data. The latter is gaining relevance due to the increasing importance and value of data.

The **object task** refers to *how* the affected flow object type is manipulated to create an output of value. We identified several functions and mechanisms in the literature and grouped them into five generic characteristics that can apply to all object types and include all possible options of manipulation without overlap, which is an essential property of classifications (Bailey, 1994). Object tasks include the creation, transition, storage, verification, and modification of flow objects.

- Examples for the *creation* of objects are the production of physical assets or services, such as using additive manufacturing technology (Chan *et al.*, 2018; Delic *et al.*, 2019) or creating information in the form of data collection (Bienhaus and Haddud, 2018). In addition, the creation of financial or legal assets is also possible, for instance, referring to novel assets like distributed ledger-based coin offerings (Xu *et al.*, 2019).
- *Transition* refers to the geographical and intra- or inter-organizational exchange of flow objects. Physical transports, data exchange, financial transactions, and the processing of contracts are typical examples for each object type (Tsolakis *et al.*, 2019; Meyer *et al.*, 2014; Abeyratne and Monfared, 2016).
- *Storage* describes the safekeeping of objects but also the process of providing access to stored objects. Examples are physical warehousing, information storage using cloud services or data lakes, and financial accounting (Talatappeh and Lakzi, 2020; Roeck *et al.*, 2019).
- *Verification* refers to ensuring the quality, history, or identity of specific flow objects. A typical example is the certification of the origin of materials, but this also applies to the other flow object types (Helo and Shamsuzzoha, 2020).
- *Modification* refers to making changes to the specific object by changing relevant properties. Thus, it can imply physical processing using machinery or data processing, for instance, using novel approaches like machine learning (Alsghaier *et al.*, 2017). Furthermore, regarding financial flows, it could be currency exchanges or changes in a contract regarding legal assets. We also include the elimination of flow objects under modification.

Context specifications

The context dimensions account for the process's setting and can be divided based on the reviewed literature into the system complexity, organizational scope, hierarchy distribution, and the number of involved structures.

System complexity describes the uncertainty of the surroundings and the types of inputs and outputs required to process (Wu *et al.*, 2013). We differentiate the complexity of systems based on the degree of repetition, the degree of clearly defined rules, the degree of structure regarding inputs, and the scope and predictability of possible events.

- *Closed systems* are systems with the lowest complexity. Requirements regarding technological support are relatively low because the process is mainly repetitive and follows clear rules with a structured input. Examples are administrative processes in a clearly defined digital workflow without external influences or unexpected events (Bienhaus and Haddud, 2018).
- *Controlled systems* require higher levels of intelligence to fulfill processes or tasks because they are more complex and partly unstructured. However, there is a clear scope of possible events. Examples of these types of systems are robots working in a defined but partly open environment on the shop floor (Morenza-Cinos *et al.*, 2019).
- *Open systems* pose the highest challenge for process fulfillment. Inputs may be unstructured and unforeseen events may occur, so that decision-making is necessary. Examples regarding physical systems are deliveries over air or traffic. Regarding information, examples are decision-making based on unstructured data (Handfield *et al.*, 2019; Fernando *et al.*, 2018).

Organizational scope refers to the supply chain setting the problem is embedded. The organizational scope of an innovation problem is relevant as it strongly influences the way technology must be deployed and as it influences which stakeholders must be managed how. Based on different references from the reviewed literature, we define four significant types that cover existing settings and have discriminatory value against each other.

- Intra-organizational refers to supply chain processes where supply chain flows do not go beyond the organization's boundaries. Internal automation of production or information analytics are typical examples on the intra-firm level (Lai et al., 2018; Tu, 2018).
- Dyad describes the focal company's perspective with supply chain flows reaching tier-1 partners outside the organization. However, the specific company's goals are in focus under consideration of the supply chain partners' interests. Common examples of this organizational scope are product deliveries or

information flows beyond organizations (Bienhaus and Haddud, 2018; Wamba, 2012).

- Triad describes the focal company's perspective considering supply chain flows reaching tier-2 partners outside the organization. While the interests of the focal company are in focus, this scope represents the complex interplay of, for example, upstream-supplier, supplier, the customer.
- Network describes the organizational setting from a neutral, supply chain-wide perspective with consideration of the interest of the supply chain as a whole, consisting of the interests of the different organizations included. Recent examples on the network level comprise communication or data platforms along the supply chain, often deploying blockchain technology (Yang, 2019; Vu et al., 2021).

The **number of involved structures** refers to the scale of the innovation problem. It is interrelated to the before-mentioned dimension of organizational scope and describes whether the problem lies in one specific structure or multiple ones. Thus, for example, an innovation problem from the customer's perspective could occur only for one specific supplier (i.e., single dyad), or it could apply to all of its suppliers (i.e., multiple dyads).

The **hierarchy distribution** in the given organizational scope is another essential dimension of innovation problems in supply chain processes. One expert mentioned the importance of this issue as it highly influences how the innovation problem can and must be approached and which technological solutions might be suitable.

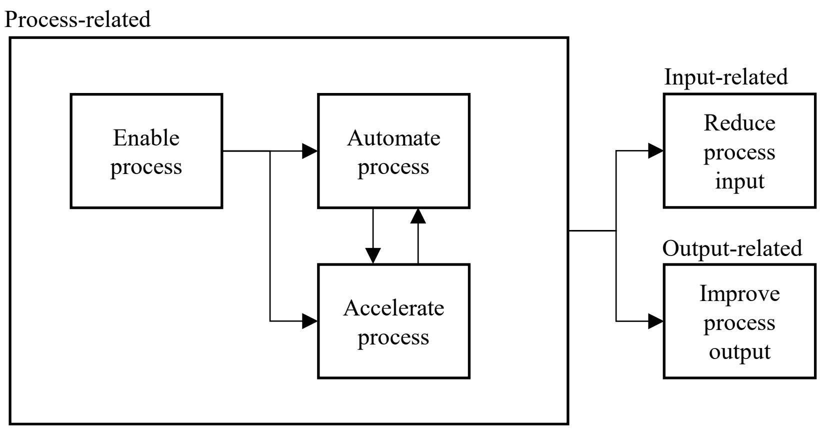
- *Advantage initiating organization* describes the setting where the organization driving the innovation has some power over the remaining supply chain partners. Often this power advantage originates in the organization's size, its relevance for the whole supply chain, or financial dependencies (Reimann and Ketchen, 2017). As a result, the initiating organization can persuade other partners for its interests with less resistance.
- *Non-existent* describes the absence of any imbalance in hierarchy or power. All involved supply chain partners are considered equal partners; decisions have to be decided on in collaboration.
- *Disadvantage initiating organization* describes the setting where the organization driving the innovation is not in a position of power in the supply chain, but

another involved organization is. As a result, initiatives cannot be forced upon other supply chain partners, and convincing those partners with more power can be challenging.

Innovation specifications

The earlier mentioned process dimensions describe what type of object is affected how so that a specific value is created. As innovation is the focus of this study, it is crucial to account for the **innovation goal** of a given process. As defined earlier, processes and their activities create an output of value based on a given input. Thus, improvement resulting from technological innovation can result either in a change in the input, a change in the output, or a change in how the process is executed. Based on these considerations and the reviewed literature, we defined five generic characteristics that describe how technology deployment can innovate supply chain processes: enable process, accelerate process, automate process, improve process output, reduce process input. *B-Figure 4* illustrates the inter-relationships between the different innovation goals.

- *Enable process* means that the technological innovation facilitates a process (i.e., a combination of flow object type and flow object task) that was not possible before. For instance, this applies to the collection of new data types due to new sensor technology (Winkelhaus and Grosse, 2019b).
- *Accelerate process* refers to the speed and timeliness of a process, e.g., data availability (van Hoek, 2019b).
- *Automate process* refers to the degree to which manual labor is necessary to perform a process or task, such as the physical handling effort or information exchange (Wamba, 2012; Hellstrom and Wiberg, 2010).
- *Improve process output* refers to the result of the process regarding quality, amount, or other relevant measures of value. Examples are data accuracy or the financial outcome of specific processes (Brinch *et al.*, 2018; Engelseth and Wang, 2018).
- *Reduce process input* refers to the resources required to perform a particular process, e.g., making it more efficient or sustainable (Yang, 2019).



B-Figure 4: Overview and inter-relationships of process innovation goals

It is important to note that the innovation goals are company-specific and depend on the individual initial situation. Thus, technology can enable a process for one company, while the same technology poses the acceleration or automation of the same process for another company.

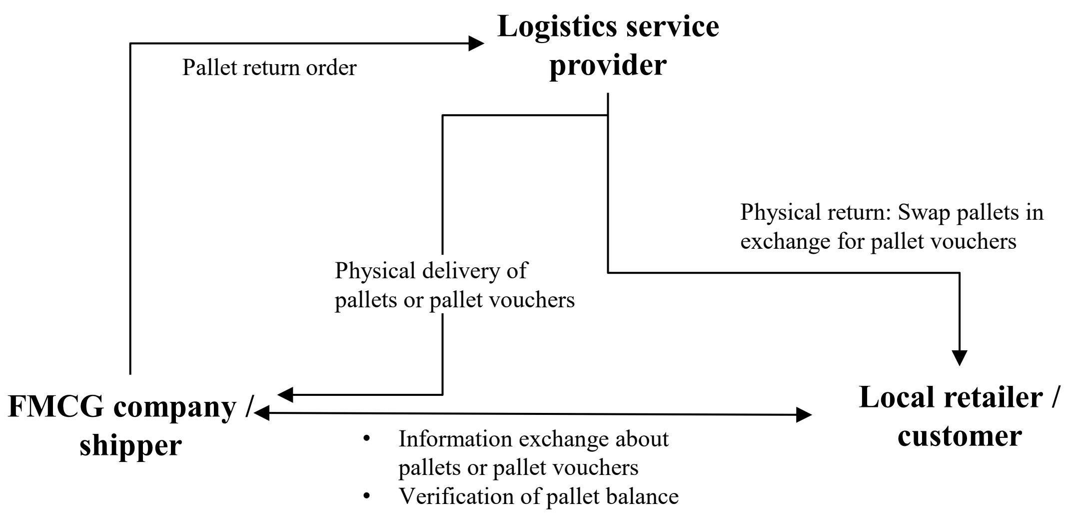
Exemplary taxonomy application

After we described the resulting taxonomy and its dimensions and characteristics in detail, we will illustrate its application using a real-world example. Generally, there are two different ways of using the taxonomy in practice or research. Firstly, it can be used to analyze existing processes and elaborate on possible ways to innovate them. This way of the application represents the ex-ante application of the taxonomy, i.e., applying it before an innovation has been implemented, which is a very relevant use-case from a practical point of view, as it allows for a structured analysis of the innovation problem at hand. Secondly, the taxonomy can be used to analyze existing process innovations in supply chains ex-post, and thus specify and analyze the innovation problem and its corresponding solution after innovation has been implemented. This use case provides an analytical tool for researchers and practitioners when examining the interplay of innovation problems and successful solutions or technologies. In the following, we will show a short example of the taxonomy's ex-ante application for an actual process and explain differences for the ex-post application.

Ex-ante application before process innovation

The case we will use to demonstrate the application of the resulting taxonomy stems from a project conducted in the period from 2018 – 2020. It comprises the business process of pallet exchange between a major FMCG company, their customer (a prominent local retailer), and a logistics service provider (LSP). From the perspective of the FMCG company, the pallet management process was very inefficient and complex, involving different supply chain flows (e.g., physical goods and pallets, pallet vouchers, information), and many media interruptions throughout the process due to the usage of different systems. Therefore, the goal was to innovate the process by simplifying and automating it while also making it more secure for all the stakeholders. Security and trustworthiness of information were important in this case, as the pallet balance has significant financial implications for all stakeholders.

When analyzing the current process in more detail, several crucial sub-processes were identified: physical handling of goods and pallets, information transmission (e.g., return orders for pallet lots), and the verification and storage of information (e.g., the verification of issued pallet vouchers or verification of the communicated pallet balance). *B-Figure 5* shows a simplified illustration of the pallet management process and relevant sub-processes.



B-Figure 5: Case example of inter-organizational supply chain process (simplified illustration)

For each identified sub-process, we can use the taxonomy to identify and classify the underlying innovation problem.

For example, the information exchange about the pallet balance is classified as the "transition" of "information" (process dimension) in a "closed system" (i.e., e-mail messaging system). The context can be defined as reaching beyond organizational boundaries in a “single dyad”, as the problem only occurs in this particular relationship. The initiating company had a “disadvantage regarding the hierarchy distribution” in this setting, although the FMCG company was a well-known brand (context specifications). Regarding the innovation specification of this particular sub-process of information exchange, “automation” is defined as the most relevant as the overarching goal of the project was to simplify and reduce manual handling.

Another example is the crucial sub-process of verifying the pallet balance. The process can be classified as object type “information” and object task “verification”. While the context still can be specified as a “single dyad” with a “hierarchical disadvantage for the initiating organization”, system complexity poses higher as verifying the pallet balance involves accessing different data sources such as the latest updates of the balance physical pallet vouchers. Thus, the system complexity is classified as a “controlled system”. As mentioned before, security and trust are one main goal for the process innovation, so that the innovation specification can be classified as “improve process output”, i.e., the quality of the verification or the reliability of the output.

Based on this analysis, options for innovating these sub-processes can be searched. For example, the information exchange regarding the pallet balance could be automated by sending daily automatic updates using the existing or new e-mail software. Another possibility to automate would be to share the current information about the pallet balance on a cloud-based platform, where both parties can access it.

Ex-post application of already implemented process innovation

Similarly, as with the ex-ante application of the taxonomy, the taxonomy can be applied to decompose and analyze already implemented process innovation. Ex-post application is beneficial when analyzing best practices for research purposes or benchmarking in practice. In contrast to ex-ante analysis, where no solution for the innovation problem is known, all dimensions and characteristics, including fitting technological and structural solutions, can be observed during the ex-post application. Thus, it can serve for finding a solution based on existing best practices or identifying patterns between innovation problems and solutions in research.

Contributions and limitations

From a theoretical perspective, our contribution is threefold. Firstly, and most importantly, we contribute by providing a better understanding of the problem space of the task-technology fit-model with particular regard to SCM. Earlier in this paper, we formulated the need to expand TTF beyond the individual level onto the process level and apply it to a supply chain-specific context. We pave the way towards reaching this supply chain-oriented TTF model by allowing for specific and rigorous operationalization and measurement of the problem space. Future research can use these to investigate further the inter-relationship of this problem space with the solution space (i.e., the characteristics of available supply chain technologies). Ultimately, this contributes to theorizing the relationship between innovation problems in supply chain processes and technologies in a formal way to predict the outcomes of technology deployment and improve technology adoption decisions.

Secondly, a contribution of the taxonomy lies in its scientific utility (Corley and Gioia, 2011). It allows researchers to clearly define and classify their unit of analysis when researching the field. This way, the taxonomy enhances conceptual rigor in future research by allowing researchers to specify their ideas more precisely. The proposed taxonomy enhances the potential to operationalize and test relevant constructs related to innovation problems when analyzing process innovation in supply chains.

Thirdly, the paper provides a rigorous conceptualization of process innovation problems in supply chains concerning technology deployment by integrating and structuring existing knowledge. To the best of our knowledge, this has not been done in this way so far. The paper takes an in-depth perspective on supply chain processes and their innovation problems, contrary to existing research, which views them as black-box constructs. Innovation problems in existing research are widely treated in a "one-size-fits-all" manner. We theorize that the different specifications of innovation problems impact their relationships, e.g., on the technologies that fit them and specific outcomes, measurement, or how they should be researched in general. Thus, a more fine-grained classification of innovation problems as we propose it in our taxonomy provides a theoretical contribution in this regard and paves the way for new research (Fawcett *et al.*, 2014).

From a practical point of view, this study contributes to existing knowledge in two ways. Firstly, it builds knowledge by providing a common understanding of the term *process innovation problem* and thus makes the construct accessible to practice and supply chain managers specifically. Also, the research puts the problem-aspect of innovating processes into the focus and gives it the necessary attention, as only if the problem is understood correctly, a fitting technological solution can be found.

Secondly, building on the need for more detailed problem understanding, the taxonomy serves as a practical tool that facilitates systematic definition, comparison, evaluation, and analysis of process innovation problems. As shown in the short example in the taxonomy application section, the theoretical value of the taxonomy is directly applicable to real-world problems, which is an essential aspect of theoretical contributions (Corley and Gioia, 2011).

Our research has some limitations that provide avenues for future research. The dimensions and characteristics of the taxonomy are derived based on scientific publications. Although we focused on empirical studies and used expert workshops and interviews for evaluation, future research should apply the taxonomy to a higher number of real-world use-cases. This way, the applicability can be verified, and missing dimensions or characteristics can be identified. Also, we designed the taxonomy to contribute to the overall goal to enable the allocation of technologies to specific innovation problems based on TTF. Future research should further develop the proposed supply chain-oriented TTF model by operationalizing the solution space and matching technologies to specific manifestations of innovation problems in the taxonomy.

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Appendix C – Study C

Towards a process-technology fit in supply chain management – a theory-driven approach to understanding Industry 4.0

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Purpose: Supply chains are predicted to face severe disruptions due to the deployment of Industry 4.0 technologies. However, a theoretical understanding of Industry 4.0 in supply chain processes and sensemaking of their benefits is still widely missing in the existing literature. Therefore, we utilize task-technology fit theory (TTF) to explain successful technology deployment in specific supply chain innovation problems.

Design/methodology/approach: Informed by task-technology fit theory, we generate a framework of process-technology fit in supply chains. Subsequently, we assemble a dataset of real-world use-cases containing successful technology-enabled process innovation in supply chains. Finally, we use quantitative cluster analysis to derive and interpret archetypical innovation problems and corresponding solutions.

Findings: Based on the conceptually derived framework, the quantitative analysis results in seven clusters of innovation problems, fitting technologies that have proven to innovate them successfully, and indications about the general characteristics of these technologies.

Research limitations/implications: We provide useful and empirically derived archetypes of innovation problems in supply chain processes. This way, the paper supports future research to analyze these different archetypical clusters in-depth. Moreover, to the best of our knowledge, our findings are among the first to provide specific insights on the inter-relationship of process characteristics and technology characteristics in supply chain processes.

Practical implications: The study reduces the complexity of Industry 4.0 applications by breaking them down into seven manageable clusters. Practitioners can use the resulting clusters to classify their organization's problems, analyze similar problems, and find fitting technological solutions based on our empirical insights.

Original/value: This study is among the first to apply task-technology fit theory to a supply chain context on a process level. Therefore, it provides theory-driven insights into the deployment of Industry 4.0 technologies in supply chains, which are scarce to this date.

Keywords: digitalization, Industry 4.0, task-technology fit, theory-driven, process innovation.

1. INTRODUCTION

The environments of supply chains are more volatile, uncertain, complex, and ambiguous (VUCA) than ever. To face the challenges of this new "VUCA"-world, supply chain managers need to improve the agility and resilience of their supply chains while maintaining a high level of cost efficiency (Bennett and Lemoine, 2014). In addition, increasing expectations regarding service, individuality, customization, granularization of orders, and delivery concepts amplify competition between companies and whole supply chains (Alicke *et al.*, 2016; Marinagi *et al.*, 2014). Thus, supply chain managers face enormous pressure to improve their supply chain processes using emerging technological advances constantly.

However, organizations struggle to harness the potential of emerging technology to innovate their supply chain processes (Geissbauer *et al.*, 2020). In recent years, much research investigated the interplay of supply chain processes and emerging technologies from different perspectives, and Industry 4.0 has become an increasingly popular topic among researchers and practitioners. However, most research has focused on describing different technologies and analyzing their functions in a specific field. Although some general classifications or categorization attempts can be found (e.g., Ghadge *et al.*, 2020; Jain and Ajmera, 2020), existing studies do not theorize on the deployment of Industry 4.0 technologies in supply chains. Recent calls for papers state the need for theory-driven approaches to understanding emerging technologies in SCM and theories that explain how managers approach the potential of particular technologies (Bourlakis *et al.*, 2020).

Literature on fit can be identified to have great potential to address these needs and improve technology adoption decisions to innovate supply chain processes. The concept of fit and related theories hold the potential of anticipating the performance impacts of possible technology deployment. In this regard, especially the task-technology fit (TTF) theory, as suggested by Goodhue and Thompson (1995), is relevant because they provide the basic constructs for analyzing technology deployment and insights into their relationships. However, so far, the model has mainly been applied to individuals or groups of individuals using information systems. Under consideration of recent advances in technology and automation, an extension of TTF to tasks in general without delimiting the focus on individuals seems necessary. Especially so, since by now, even complex cognitive tasks can be fulfilled by emerging technological systems. Also, applications of the model are restricted mainly to business processes without physical integration. Literature has not discussed TTF on tasks or processes that incorporate integrated supply chain flows, i.e., materials, information, and financial assets transferred beyond company borders in a supply chain-oriented fashion.

Also, despite the keen interest in Industry 4.0 and its application in supply chain processes, extant research mainly focuses on its technological implications (Bourlakis *et al.*, 2020). However, there is still a lack of research focused on the specific, individual applications of Industry 4.0 technologies. A large number of existing Industry 4.0 use-cases in supply chains undermines their vast potential. However, this also leads to a high degree of complexity, which may impede systematic analysis in research and effective management in practice. This problem applies to business leaders who need to identify tangible projects to implement Industry 4.0 in their supply chains. To reduce this complexity, we propose clustering the high number of individual use-cases of Industry 4.0 applications into overseeable and manageable groups. Thus, we aim at theorizing the relationship between technology and the application area.

Several studies to structure Industry 4.0 and supply chain management (SCM) have been conducted in the past. However, their focus either solely lies on technological or strategic considerations. Also, most existing classifications are not derived from an empirical analysis but instead developed solely on a conceptual basis, which hinders their use to identify tangible projects.

To address the beforementioned gaps, this study aims to contribute to the existing classifications on the interface of Industry 4.0 and SCM in two ways. Firstly, the classification subjects are specific real-world use-cases described by the combination of both the field of application and the technology utilized. Secondly, the resulting clusters of Industry 4.0-enabled innovation in supply chains will be derived empirically rather than conceptually based on quantitative cluster analysis.

Given the relevance of the topic and the shortcomings of extant literature, this study aims to address the following research questions:

RQ1: What are representative types of technology-enabled process innovation in practice based on their constituting characteristics?

RQ2: How can the fit between innovation problems in supply chain processes and technology characteristics be described formally?

To answer these questions, the remainder of this study is as follows. The next section summarizes existing literature related to similar classification approaches and theoretical models related to technology and fit. The third section provides a detailed description of the methodology followed during the research process. The fourth section describes the study results, namely the resulting seven clusters, including a description and interpretation. Lastly, the paper concludes with contributions, limitations, and propositions for future research.

2. REVIEW OF PREVIOUS RESEARCH

Existing classifications of technology-enabled innovation in supply chains

This study utilizes clustering as a form of classification to theorize on the inter-relationship between Industry 4.0 deployment, innovation problems, and performance outcomes. Hence, it is essential to review existing classifications considering technology-enabled innovation in supply chains. Two groups of existing classifications can be distinguished in the literature. One focuses on the classification of technologies, while the other focuses on processes or fields within SCM.

Existing classifications of technologies deployed in SCM investigate the phenomenon of innovation in supply chain processes from the solution perspective. Therefore, publications in this group provide taxonomies of specific technologies. For instance, Leveling *et al.* (2014) provide a taxonomy of big data analytics in SCM that distinguishes areas of application, potential benefits, and types of data. Also, Paliwal *et al.* (2020) provide a taxonomy of blockchain applications for sustainable SCM based on a systematic literature review. Besides specific technologies, other publications classify Industry 4.0 technologies as a whole, as Fatorachian and Kazemi (2021) investigate the impact on supply chain performance. Another example for classifications of Industry 4.0 in a specific context is given by Perales *et al.* (2019). The authors classify Industry 4.0 to investigate the enhancement of sustainability in agri-food supply chains.

The second group of existing classifications focuses on processes, topics, or fields within SCM and thus has a problem-oriented perspective on process innovation in supply chains. In this context, a few major SCM frameworks and models are to mention. For example, Cooper *et al.* (1997) provided an early framework including SCM's business processes, management components, and supply chain structure. Bowersox *et al.* (1999) focused on referencing different supply chain flows and referencing technology in SCM. Other seminal frameworks or models of SCM are provided by Mentzer *et al.* (2001) and Skjott-Larsen *et al.* (2007). However, these rather aim at understanding SCM as a whole from a higher-level perspective. Besides these generic frameworks, more specific classifications on sub-streams of SCM like information flow strategies (Vanpoucke *et al.*, 2009) and supply chain relationships or networks (Ahmed *et al.*, 2017; Lamming *et al.*, 2000) exist. Lastly, focusing on processes and tasks, the SCOR model is a widely acknowledged reference model. It classifies SCM into six major management processes and refines them into detailed sub-processes, including corresponding inputs and outputs (Huan *et al.*, 2004).

Regarding in-depth classifications of processes or tasks in SCM and technology deployment, existent publications are minimal. Walton and Gupta (1999) provided a framework especially for matching the benefits of EDI technology with a company's effort in an SCM context. Nuss *et al.* (2015) presented a classification scheme for planning tasks in reverse logistics.

However, to our knowledge, existing literature fails to provide a generally applicable classification of Industry 4.0 applications in supply chain processes. Especially so regarding classifications that allow for in-depth analysis of supply chain process innovation. Supply chain innovation is usually researched from a higher-level perspective, viewing process innovation as a "black box-construct. Thus, a problem-oriented classification, which is independent of specific technologies, is necessary for SCM literature. Moreover, since much hype and overly optimistic expectations regarding Industry 4.0 exist, we strongly suggest the empirical elaboration of archetypes of Industry 4.0 deployment in supply chain processes to enable theorizing on the fit between technology and innovation problem characteristics on a realistic basis.

Technology deployment and performance

In literature, the concept of fit is widely used to describe the inter-relationships of different constructs that lead to specific outcomes. For example, contingency theory states that the design of an organization must fit with the environment and its sub-systems. However, it was applied to many other contexts and promotes the general notion that there is no single best way to manage a situation (Fiedler, 1964). Another example is organizational information processing theory. It identifies three essential concepts to explain how organizations deal with complex and dynamic environments: information processing needs, information processing capability, and the fit between the two to obtain optimal performance (Premkumar *et al.*, 2005).

Several models exist explaining the interplay of technologies and their surroundings regarding the specific relationship between technology and performance. In their meta-analysis paper, Heine et al. (2003) identified 16 different models investigating the relationship between technology and performance. Results of these models vary widely regarding their level of analysis, which reaches from individuals, groups, and processes to whole organizations. Also, identified models vary in their definition of technology, either analyzing the relationship for a particular technology or a very holistic view on technology, including processes and people. Lastly, models differ regarding their measurement of performance, containing subjective and objective measures. Heine *et al.* (2003) find that these inconsistencies in construct definitions make it especially hard to compare the findings and build upon existing research in this field.

Four models can be identified dealing explicitly with the fit between technology usage and performance, while others express technology in terms of moderation or mediating relationships. These four models are the task-technology fit model (Goodhue and Thompson, 1995), independent effects model (Georgantzas and Shapiro, 1993), effects of employee skills on AMT performance model (Pagell *et al.*, 2000), and process-technology fit on manufacturing performance model (Das and Narasimhan, 2001).

For this study, the models of Goodhue and Thompson (1995) and Das and Narasimhan (2001) seem most relevant because they explicitly focus on processes or tasks and allow ex-ante evaluation of technology deployment in a specific context. Das and Narasimhan (2001) investigate the fit between process environment and advanced manufacturing technology (AMT) and the resulting impact on manufacturing performance. They elaborate ideal types of aligned process environments and AMT investments leading to superior performance. However, their findings are particularly concerning manufacturing processes, differentiating between job shops and assembly lines. Also, their study is particular regarding the technology definition, solely focusing on AMT. Thus, their findings are not fully applicable for a supply chain setting with inter-organizational processes and are not suitable for the different Industry 4.0 technologies.

On the other hand, the task-technology fit model (TTF) from Goodhue and Thompson (1995) provides a more holistic approach towards the topic. It describes the relationship between capabilities of information systems (IS), requirements of user tasks, and individual performance of the user. It states that the higher the degree of fit between information system (IS) capabilities and task requirements, the better the system deployment's performance impact (Goodhue and Thompson, 1995). TTF was first published by Goodhue and Thompson (1995) and proved the TTF measure, in conjunction with utilization of the system, improves job performance and effectiveness of individuals significantly. The authors identified eight dimensions of TTF: data quality, locatability of data, authorization to access data, data compatibility (between systems), training and ease of use, production timeliness, systems reliability, and IS relationship with users. The factors focus on meeting task needs for using data in decision-making, meeting day-to-day operational needs, and responding to changing business needs. Shortly after, Zigurs and Buckland (1998) presented an analogous model for groups of individuals. Since then, a few variations of the model have been developed and applied in different contexts, posing slightly different relationships of the constructs' task characteristics, technology characteristics, fit, performance impacts, and utilization (i.e., Dishaw and Strong, 1999; Fuller and Dennis, 2009; Junglas *et al.*, 2008; Ratna *et al.*, 2018; Fu *et al.*, 2019; Huscroft *et al.*, 2013).

Achievements in TTF research can be divided into the extension of the model itself, the embedding in IS literature, and the application in different practical contexts. The model can improve the selection of technologies by anticipating the performance impacts of possible technology deployment. However, the model has not been applied to tasks or processes beyond the individual or group level, especially not in a supply chain-oriented context. Hence, we propose the development of a supply chain-specific process-technology fit model for Industry 4.0.

3. METHODOLOGY

Section 2 shows that existing literature does not provide sufficient theoretical knowledge on the relationship between Industry 4.0 technologies, application areas in supply chain processes, and performance impacts. We identified real-world use-cases as a suitable solution for this research gap based on an existing theoretical foundation.

Hence, we propose a rigorous research design following four consecutive research phases to close this identified research gap (Table 3.1):

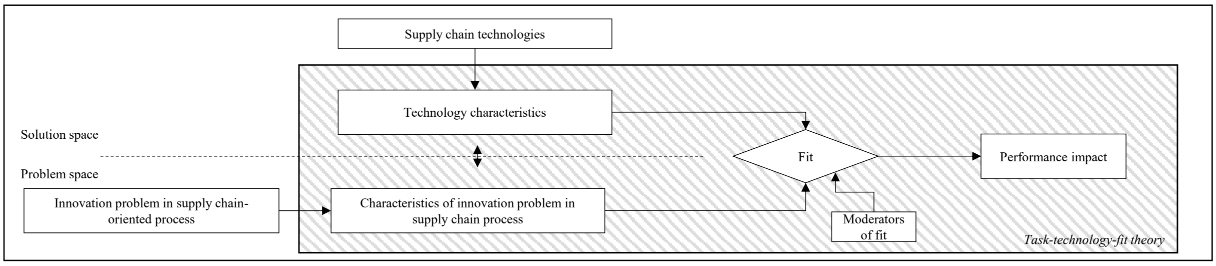
C-Table 3.1: Overview of the four consecutive research phases

	Phase 1: Development of an a priori framework	**Phase 2: Database creation**	**Phase 3: Content analysis**	**Phase 4: Interpretation of the analysis' results**
Steps	-Identify relevant literature concerning the interplay of technology deployment and performance impact. -Adapt existing frameworks and knowledge to supply chain-specific requirements. -Define data points for database creation.	-Define sources and search mode for secondary data. -Define inclusion criteria for use-cases. -Define verification approach for data points. -Conduct secondary research.	-Quantitative analysis of the data set based on the given data points. -Search for patterns and clusters.	-Qualitative description and interpretation of the derived clusters. -Additional research to elaborate derived clusters (i.e., corresponding characteristics of technologies).
Methods	Literature review	Internet-based research for secondary data.	Cluster analysis using Python 3.	Literature review and secondary data research.
Sources	Models and theories that measure the impact of technology on performance.	Databases, articles, and company websites.	-Categorical clustering literature. -Python libraries.	Results from content analysis (Phase 3), technology-specific literature.
Results	Adapted fit model describing the interplay of supply chain technologies, innovation problems in supply chain process, and performance impacts.	Data set containing 79 unique real-world use-cases of technology-enabled process innovation in supply chains.	Quantitatively derived clusters of innovation problems in supply chains and corresponding technological solutions for each cluster, based on real-world use-cases.	-Qualitative elaborated clusters of innovation problems in supply chains and matching technological solutions, including their constituting characteristics.

Phase 1: Development of an a priori framework and variable selection

To develop an a priori framework, we analyze the existing literature related to the efficient use of technology. Various models were identified that measure the impact of technology on performance in general. These models can be differentiated by: exogenous and endogenous variables, level of analysis (individual, organization, process), technology applicability (wide, medium, narrow), and performance measures (Heine *et al.*, 2003). A detailed overview of existing literature on such models was given in Section

2. As no model accounts for supply chain-specific aspects in the context of Industry 4.0, we developed a novel framework informed by task-technology fit theory (TTF) which is illustrated in Figure 3.1*C-Figure 3.1: A priori framework derived from literature* (Goodhue and Thompson, 1995).



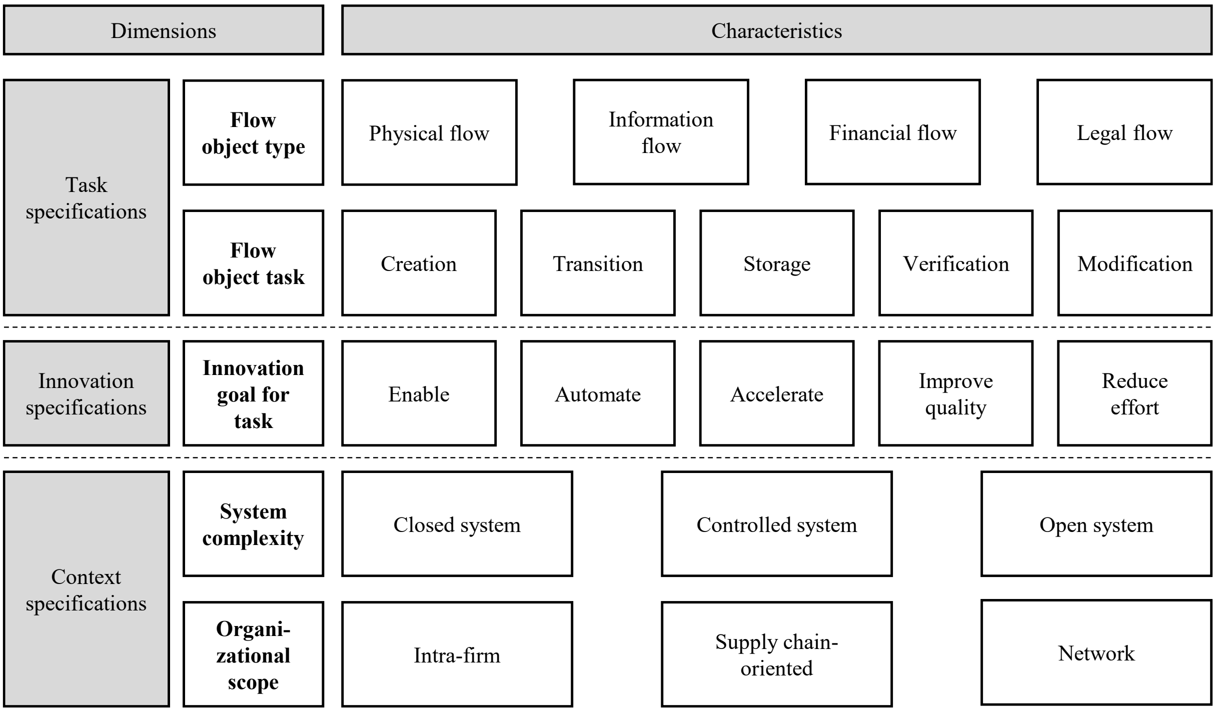
C-Figure 3.1: A priori framework derived from literature

The framework comprises three main elements: characteristics of supply chain innovation problems, characteristics of supply chain technologies, and the supply chain performance impact. TTF states that a performance impact is achieved when a fit between technology characteristics and innovation problems (i.e., tasks) is given (Goodhue and Thompson, 1995).

Based on the overall a priori framework, the variables for the cluster analysis are selected. The selection of variables to characterize the clustered objects is an integral part of cluster analysis, as the derived clusters are defined only by these variables. Thus, variables to be included in the cluster investigation must be carefully considered, including conceptual and practical aspects (Hair, 2009). Regarding the conceptual considerations, cluster analysis is a non-inferential technique that does not offer any statistical tools that indicate the significance of a solution. Hence, conceptual support is particularly crucial for cluster analysis' design and interpretation. Therefore, the variables have to be selected upon some conceptual rationale (Hair, 2009).

In our specific case, variable selection for the clustering analysis refers to the detailed characteristics of innovation problems in supply chain processes. To elaborate on innovation problem characteristics in supply chain processes in detail, we build on a previously developed taxonomy following a rigorous taxonomy development process suggested by Nickerson *et al.* (2013). The taxonomy allows the classification of supply chain innovation tasks based on five dimensions: Flow object type, flow object task, innovation goal for the task, system complexity, and organizational scope (Selensky and Hofmann, 2021). The taxonomy is illustrated in Figure 3.2.

The *task dimensions* refer to a supply chain task's specific characteristics, describing how input is processed into an output to create value. We identified nine generic characteristics to define the value creation of a task in supply chains, which can be divided into the two dimensions of flow object type and flow object task. In addition*, innovation specifications* account for desired improvements of a defined task. Thus, improvement resulting from technological innovation can result either in a change in the input, a change in the output, or a change in how the task is executed. Finally, the *context dimensions* account for the task's setting and can be divided based on the reviewed literature into the system complexity and the organizational scope (Selensky and Hofmann, 2021).



C-Figure 3.2: Characteristics of innovation problems in supply chain processes (Selensky and Hofmann, 2021)

To elaborate on technology characteristics in detail, we will rely on the operationalization of Goodhue and Thompson (1995) in their seminal paper. Namely, they characterize technologies based on the eight characteristics data quality, locatability of data, authorization to access data, data compatibility (between systems), training and ease of use, production timeliness, systems reliability, and IS relationship with users.

Phase 2: Database creation

Technical and practical implementation of the database:

Based on the developed a priori framework, a database of unique real-world Industry 4.0 use-cases in supply chain processes is created using secondary research. The collection and management of the data were conducted via MS-Access. Creating a database using secondary data is prone to be influenced by personal biases to some extent. Hence, clear instructions for data collection were formulated in written form to ensure a rigorous and reproducible research process.

Search mode:

When searching for Industry 4.0 use-cases in supply chain processes, the focus was on different technologies and their components, the application areas, and the impact. The search was organized based on the five key technologies of Industry 4.0 as identified by Winkelhaus and Grosse (2019b) in their literature review: Internet of Things, Cyber-physical systems, Distributed Ledger Technology, Machine Learning and Big Data, Mobile-based systems, and Cloud computing(Winkelhaus and Grosse, 2019b). A grid spanning these key technologies and the basic supply chain processes based on the SCOR model (i.e., plan, source, make, deliver, return, enable) was utilized for the search process. This way, all technologies in all main SCM application areas were searched during the research process. More precisely, search strings of each possible combination of these two components were built and utilized when searching the identified sources. For example, when searching use-cases for Mobile-based systems in make-processes, search strings would be:

("mobile-based" OR "handheld" or "smart device") AND ("production" OR "shop-floor" OR "manufacturing")

Additionally, depending on the used sources, different possibilities for filtering use-cases were utilized to find cases for each field in the developed grid, depending on the functionality of the platforms. Also, it should be noted that not every combination is represented equally or represented at all in practice.

Sources of secondary research:

The following sources were used for conducting the secondary research during the creation of the database of Industry 4.0 use-cases. A list of the most utilized platforms and sources for use-case research is presented in Appendix 1.

- Use-case collections from governmental web platforms
- Use-case collections from private web platforms
- Industry journals and magazines
- Use-cases published by applying companies

Sampling and inclusion criteria:

The most critical inclusion criterion for the use-cases in the database is implementing the technological solution in an organization. Hence, descriptions by technology vendors without explicit and reliable applications are excluded from the data set. Another essential inclusion criterion for the database is that only cases that provide a successful example of technology implementation and usage (i.e., successful technology-enabled process innovations) are included. Hence, some proof of success and usage by some measure must be provided in the given source. This criterion ensures that all configurations of technologies and application areas provide examples of good fit when analyzed in later phases.

Validity of data:

Accounting for representativeness is an essential factor when using cluster analysis as a research method. As mentioned above, data was collected based on five key technology trends derived from literature and based on the five major SCOR processes. However, the defined sources deliver different amounts of results for different combinations of technologies and application processes. However, also, in reality, some applications are more common than others. Hence, the database relies on the basic assumption that the applied search strategy leads to an overview of cases that somehow reflects reality, as those cases that are more common and more successful will appear during the research more often. However, we are aware that the database cannot claim full representativeness of the real world, as most databases cannot. Nevertheless, as the analysis will not rely on absolute counts of cases but the emergence of different combinations of characteristics and their content, the degree of representativeness is appropriate for the given research objectives.

Phase 3: Content analysis

The resulting database from phase 2 is analyzed using Python 3. Hierarchical cluster analysis is used to partition the Industry 4.0 use-cases into groups based on their underlying supply chain innovation problems. Since the hierarchical cluster algorithms are considered superior when there is no prior specification or initial starting point, a hierarchical cluster analysis procedure was used to determine the candidate number of clusters. Ward's method with Euclidean distance measure, considered superior among hierarchical cluster methods, was adopted (Punj and Stewart, 1983). The clustering was conducted based on the five variables characterizing the innovation problems in supply chain processes: *Flow object type*, *Flow object task*, *Innovation goal for the task*, *System complexity*, *Organizational scope*.

One of the critical issues in cluster analyses is the determination of the appropriate number of groups. The general idea is to balance the two fundamental properties of clusters: external isolation and internal cohesion (Cormack, 1971). Different numbers of clusters were tested quantitively but also by the researchers' intuition during this research phase. The analysis of the dendrogram suggested that seven clusters are appropriate for the data. The seven-cluster classification scheme was thus used in all subsequent analyses.

Although the classification approach adopted in this study is considered robust, it is necessary to demonstrate that the identified clusters are meaningful and useful. Several methods are available to test the quality of the clustering solution (Milligan, 1981). We validated the resulting clusters using the Hopkins Test and the expertise and intuition of the researchers.

Phase 4: Interpretation of data and derivation of the final framework

The last phase of this study includes the qualitative description and interpretation of the quantitively derived clusters. While doing so, striking patterns in the characteristics of the innovation problems in each cluster are examined. Also, the data points *technology* and *description* from the database are evaluated for each cluster during this phase. Hence, we identify constituting properties of each group. Then, additional research is conducted to draw a picture of the characteristics of assigned technologies for each cluster. Lastly, based on the qualitative analysis of the use-cases, we classify the relevance of the eight technology characteristics identified by Goodhue and Thompson (1995) on a simple scale for each cluster. This way, the link between innovation problems (i.e., cluster of innovation problems) and characteristics of supply chain technologies can be described more formally and precisely.

4. FINDINGS

The research phases 1 and 2 resulted in a dataset of 79 unique and successful cases of technology-enabled process innovations in supply chains. We extracted the underlying innovation problem of each case using our ex-ante framework presented in Section 3 and identified the technologies solving the innovation problem from the corresponding sources. The selected cases spanned various industries and countries. They originated from different sources, mainly from existing databases such as the "Plattform Industrie 4.0" from the Federal Ministry of Economic Affairs and Energy in Germany or the "IoT One" database. A list of the most relevant sources can be found in Appendix 1. Additionally, cases were searched and supplemented from articles and company websites.

In research phase 3, we clustered the data set with Ward linkage and Euclidean distance, identified as the best fit for our dataset. After experimenting with different cluster sizes and validating results, quantitatively using the Hopkins-Test and qualitatively using intuition and expertise of the researchers, a seven-cluster solution seems most appropriate for the given dataset. The dendrogram illustrating the clustering hierarchy and the corresponding seven-cluster solution is illustrated in Appendix 2. Consequently, we follow the described methodology with an interpretation of the resulting clusters (phase 4).

Interpretation of the data: towards archetypes of technology-enabled innovation in supply chain processes

In the following, each of the seven quantitively derived clusters will be interpreted and extended qualitatively. For each, we will first summarize the content and describe and interpret the predominant characteristics in each cluster. Subsequently, we add qualitative knowledge from the use-case descriptions and transfer the analytical findings to the real-world applications of the use-cases. Lastly, we analyze the technologies deployed in each cluster and assess the relevance of the eight technology characteristics identified by Goodhue and Thompson (1995). With this last step, we can generically link technology characteristics directly to clusters of innovation problems, thus theoretically explaining why specific configurations pose successfully. A comprehensive table showing all the use-cases and their characteristics for each cluster can be found in Appendix 3.

Cluster 1: "Enable inter-organizational flow tasks in open systems."

Characteristics of innovation problem: The dominant characteristics in Cluster 1 comprise the enablement as innovation goal in open and thus complex systems. The flow object tasks differ but mainly focus on the creation of information and also the verification of physical flows. Notably, the organizational scope goes beyond the firm level in every case, spanning direct supply chain partners or the whole network.

Analysis of use-cases: It can be observed that the use-cases most dominantly comprise tracking, tracing, or monitoring solutions of different information types. Examples of these information types are the geographical position, temperature, or identity of physical goods. Creating information and granting access to new information types for different stakeholders is especially relevant regarding the tasks. However, the timeliness of information (i.e., real-time accessibility) also often plays a role when reviewing the use-cases qualitatively.

Analysis of technologies deployed: Technology-wise, this cluster seems highly reliant on sensor technologies such as geographical or smart sensors and automatic identification technologies that allow the creation of this information of the physical world. Additionally, the verification of physical flows relies on distributed ledger technologies. Based on the qualitative analysis of the use-cases, we classified the importance of the eight technology characteristics identified by Goodhue and Thompson (1995) on a simple scale for Cluster 1. It can be observed that *data quality*, *authorization to access data* by different stakeholders, *data compatibility* between different systems are the critical characteristics of technological solutions in this Cluster 1.

Cluster 2: "Enable information storage in and beyond organizations."

Characteristics of innovation problem: Cluster 2 exclusively consists of use-cases considering the information flow and, more precisely, information storage. Most use-cases pose an innovation by enabling this storage and the reduced effort of storing information and granting access to it. However, use-cases vary regarding the complexity of systems they store information from and the organizational scope, which spans the intra-firm and supply chain-oriented and network levels.

Analysis of use-cases: The use-cases in Cluster 2 mainly relate to aggregating previously collected or created information. Moreover, the cases often involve some form of accessibility or visualization of the stored aggregated data. While intra-firm solutions often describe some form of dashboard or monitoring system for stored data, network solutions mainly comprise platforms or similar software. Examples are condition monitoring solutions of robotic systems at the intra-firm level and logistics data platforms at the network level.

Analysis of technologies deployed: Important technologies in Cluster 2 comprise cloud computing, digital (software) platforms, and data centers, but also distributed ledger technologies and smart mobile applications for decentralized data storage. Reviewing these technologies and analyzing their most relevant characteristics, *locatability of data* (i.e., where to find relevant data), *authorization to access data* (especially in an inter-organizational context), and *data compatibility* (to merge data from different sources on the platforms) pose the key-characteristics in Cluster 2.

Cluster 3: "Create and transfer information along supply chains."

Characteristics of innovation problem: Cluster 3 predominantly addresses information flows in supply chains. Regarding the tasks to fulfill with information flows, the cluster considers the creation and transition of information. The innovation of these two tasks is achieved by enabling, accelerating, or automating the creation or transition of information in organizations or between supply chain partners. Furthermore, the context of these tasks is closed or controlled, thus posing a manageable complexity, while very complex open systems are out of scope.

Analysis of use-cases: When analyzing the use-cases in more detail, several sub-clusters emerge from Cluster 3. Firstly, considering the transition of information flow. Automation of these transitions, for example, comprises examples of automated re-orders between supply chain partners using Kanban or similar concepts. Acceleration of information transition mainly relates to intra-firm problems, where shop-floor workers are provided with the necessary information faster, for example, through smart mobile devices. Finally, other use-cases enable and automate the creation of digital information.

Analysis of technologies deployed: As specific cases in this cluster differ, so do the technologies deployed. The main groups of technologies dealing with the creation and transition of information are smart wearables that provide information for individuals, sensors and machine learning algorithms that enable and automate the creation of information, and (DLT-based) platform solutions that enable and automate the transition of information between organizations. *Data quality* is among the most relevant characteristics of the technologies solving problems in this cluster. Moreover, a review of the use-cases showed that these technologies also pose a high interaction with human users, and thus the two characteristics *training and ease of u*se and *IS relationship* with users seem crucial to achieving performance impact in the supply chain process.

Cluster 4: "Improve output of information handling in organizations."

Characteristics of innovation problem: The use-cases in Cluster 4 are very homogenous and deal with the modification of information, whereas technological innovation improves the quality of this modification. Practical innovations in this cluster contain closed or controlled systems, leaving complex open systems out of scope. Also, the cluster focuses on intra-firm innovation of information flow modification.

Analysis of use-cases: Analyzing the use-cases in detail, they comprise topics like route optimization, maintenance planning, or data analysis for various improvements. While these different types of data modification and optimization problems were solvable somehow before, emerging technologies offer more precise solutions for these issues.

Analysis of technologies deployed: Technologies that offer a higher quality output of information modification tasks comprise modern software using machine learning algorithms and suitable hardware that can handle large amounts of information. The analysis of the cases and deployed technologies identified *data quality*, *production timeliness*, and *IS relationship with users* as the most critical technology characteristics innovating this cluster. Data quality thereby relates to the quality of output. Production timeliness relates to the fulfillment of expected turnaround times, which are essential for deployment in day-to-day operations. As these systems have interfaces with users that act upon their output, relationship with users poses particularly important to achieve performance impacts, based on the identified use-cases.

Cluster 5: "Improve the physical dimension in organizations and supply chains."

Characteristics of innovation problem: Cluster 5 predominantly addresses physical flows in or between organizations in closed or controlled systems. Tasks regarding the physical flow differ regarding the creation, modification, and verification, and these tasks are innovated either by enabling the task, accelerating it, or automating it. More seldom, the innovation comprises reducing the effort to modify a physical flow or improve the quality of its verification.

Analysis of use-cases: Regarding creating physical flows, use-cases mainly derive from manufacturing and address topics like enabling new designs by additive manufacturing to produce unique parts, accelerating individual prototyping, or automating production and assembly lines. Regarding verifying physical flows, use-cases comprise origin tracing of goods (e.g., diamonds) and certification of physical characteristics. Depending on the current state in each industry or supply network, technologies enable this verification or automate and accelerate it to improve efficiency.

Analysis of technologies deployed: For creating physical flows, mainly additive manufacturing, robotics, and intelligent machinery systems seem relevant based on the use-cases. Verification of physical flows and characteristics is mainly solved by DLT-related solutions that enable trust among supply chain partners. The technology characteristic of *production timeliness* is especially relevant for the physical flow use-cases, while *authorization to access data* is vital for verification cases. *Systems reliability* was found crucial for all the use-cases contained in Cluster 5.

Cluster 6: "Automate physical storage on the organizational level."

Characteristics of innovation problem: Cluster 6 contains very similar use-cases concerned with the physical storage on an intra-firm level. Innovation of the use-cases aims at automating these physical storage activities.

Analysis of use-cases: Although having very similar characteristics, the use-cases comprise different aspects of storage automation and different ways to solve this issue technologically. For example, some solutions automate the picking process of stored goods, helping the human workers. Others automate intra-logistic transport, while a third group automates and optimizes warehousing holistically by deploying an overarching system.

Analysis of technologies deployed: For the automation of physical intra-logistic storge, mainly intra-logistic robots (i.e., autonomous transport systems) and intelligent warehouses are deployed. For these technologies, *production timeliness*, *reliability*, and *relationship with the users* (i.e., collaboration with shop-floor workers) were identified as critical characteristics when reviewing the use-cases.

Cluster 7: "Improve the physical transport in open systems."

Characteristics of innovation problem: Cluster 7 predominantly deals with physical transport in open systems between organizations. This transport is either innovated by being automated, accelerated, or by reducing the resources necessary to perform it.

Analysis of use-cases: The predominant characteristic "open system" in this cluster refers to the real world the transport is taking place (i.e., road traffic or airspace). In contrast to the intra-logistics use-cases from Cluster 6, these open systems cannot be controlled and thus pose a high complexity for technological solutions. All the use-cases comprise the physical delivery (case 175 legal flow can be viewed as an outlier in the cluster) that either take place between locations of one organization or between different organizations. Cases like autonomous truck delivery or unloading mainly aim to reduce human interaction (i.e., automation), while the delivery of more miniature goods (e.g., by drone delivery) mainly aims to accelerate the delivery task. Lastly, modern transport concepts like truck platooning or sustainable delivery robots aim at reducing the input of physical delivery.

Analysis of technologies deployed: Technologies in Cluster 7 can be summarized as autonomous vehicles operating in open, often unknown, and complex systems. They comprise different sub-technologies included in autonomous trucks or trains, delivery- or (un-)loading- robots, drones, and technological systems used to optimize these delivery tasks through software and sensor technology. For these systems, *timeliness* and *reliability* were identified as essential to achieve the expected performance improvements.

Table 4.1 summarizes the findings of predominant technology characteristics in each of the resulting clusters. Analyzing the table line by line highlights the different importance of each characteristic in the different clusters. For example, data quality seems to play a crucial role for Cluster 1, Cluster 3, and Cluster 4, while it has no importance for Cluster 2, Cluster 6, and Cluster 7.

C-Table 4.1: Overview of predominant technology characteristics per cluster

Technology characteristics	**Cluster 1: Enable inter-organizational flow in open systems.**	**Cluster 2: Enable information storage.**	**Cluster 3: Create and transfer information along supply chains.**	**Cluster 4: Improve output of information handling.**	**Cluster 5: Improve the physical dimension.**	**Cluster 6: Automate physical storage.**	**Cluster 7: Improve physical transport in open systems.**
Data quality	++	0	++	++	+	0	0
Locatability of data	+	++	+	+	0	0	+
Authorization to access data	++	++	0	0	++	0	0
Data compatibility	++	++	0	+	0	0	+
Training and ease of use	0	0	++	0	0	+	0
Production timeliness	+	+	+	++	++	++	++
Systems reliability	++	+	0	0	++	++	++
IS relationship with users	0	0	++	++	+	++	0

5. CONCLUSION

As stated in the beginning, the goal of this study was twofold. We first aimed to derive practical groupings of innovation problems in supply chain processes using quantitative clustering. Secondly, we wanted to use these archetypical clusters to theorize on the fit between innovation problems and technology characteristics. We did this by analyzing successful configurations of innovation problems and technologies.

Regarding the first goal, the quantitative clustering of the database revealed seven clusters of similar innovation problems based on defined characteristics. The qualitative analysis of these clusters showed that, in sum, the clusters are meaningful and valuable. Moreover, each cluster could be interpreted and enlarged with further research. Thus, we contribute to theoretical knowledge by providing useful archetypes of innovation problems. Researchers can use these to define and classify their unit of analysis more precisely. The paper hence provides a foundation for future research to analyze these different archetypical clusters in-depth.

We could add to the theoretical knowledge regarding the second goal by linking the resulting clusters of innovation problems with specific technologies. Furthermore, we linked the innovation problems with the characteristics of the technologies successfully deployed in these clusters. Thus, the results provide the first step towards a theoretical explanation of the technological characteristics necessary to solve specific, practice-based innovation problems in supply chain processes. The paper contributes to elaborating a supply chain-oriented process-technology fit model based on task-technology fit theory. To the best of our knowledge, our findings are the first to provide specific insights on the inter-relationship of process characteristics and technology characteristics in supply chain processes. While some research on this topic exists, it either focuses on specific technologies or processes only, does not provide specific consideration for inter-organizational processes, or only theorizes on the level of individuals or groups instead of processes. Hence, this study contributes to theory by providing an empirically based conceptualization of technology-enabled process innovation in supply chains, which has not been done in this way, as far as we know.

From a practical perspective, the study reduces the high complexity related to Industry 4.0 applications by breaking down many different problems and solutions into seven manageable clusters. This allows clear communication on the topic, structured analysis of problems, and efficient solutions design. More precisely, practitioners can use the resulting clusters to classify their organization's problems. Furthermore, they can analyze similar problems abstractly and find fitting technological solutions based on our empirical insights on which problem types can be innovated efficiently by specific technologies. Finally, practitioners can use this knowledge to focus their attention during the technology pre-adoption phase when facing a specific problem.

Of course, this study has some limitations. First of all, as stated in Section 3, we applied the general assumption that use-cases in the database are positive examples of technology deployment (i.e., examples where a fit between innovation problem and technology is given). As we created the dataset based on secondary data, this assumption cannot be considered as always given. However, as described in Section 3, we mitigated this risk through a rigorous and clearly defined data sampling process. Another issue poses the representativeness, balance, and size of the dataset, as with most studies relying on quantitative clustering. In the current dataset, a strong dominance of use-cases dealing with physical and information flows can be observed. It can be argued that this imbalance somehow reflects reality, as these cases are further developed and more common than cases dealing with financial or legal flows. However, it is difficult to determine the correct design of a balanced and representative dataset precisely.

Further research should consider these issues by deploying a larger dataset to the proposed methodology. Also, the derived technology characteristics of each cluster should be evaluated in more detail, for example, using expert interviews or in-depth case studies. Finally, regarding the clustering itself, linkage methods such as single linkage, which tend to maintain singleton clusters high up the hierarchy, may be used to identify outliers. The outliers may then be excluded from the dataset and either the same or another algorithm applied to the reduced data set. To keep the complexity of the analysis reasonable, we have refrained from following such an iterative approach, but it may be useful for future studies.

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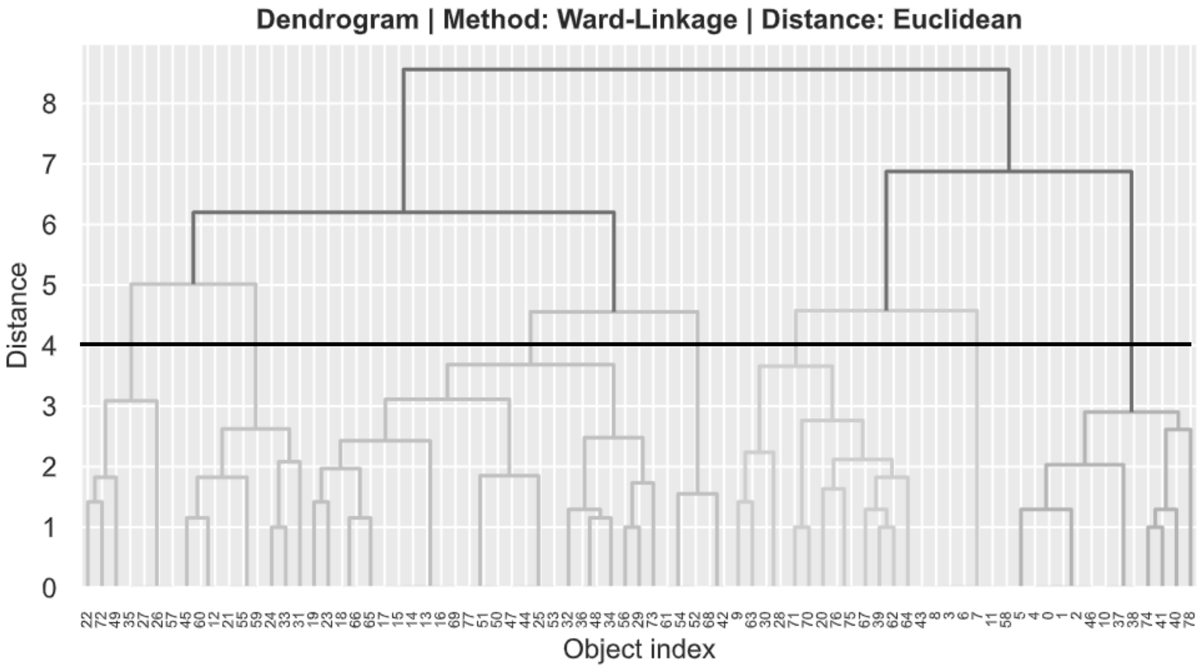
Study C – Appendix 1. Sources used during dataset creation (most important)

Source	Comment / Information
https://industrie-4-0.ul.com/use-cases-page/	Company website providing Industry 4.0 use-cases
https://www.plattform-i40.de/PI40/Navigation/Karte/SiteGlobals/Forms/Formulare/EN/map-use-cases-formular.html	German platform providing Industry 4.0 use-cases
http://www.industrie2025.ch/	Swiss platform providing Industry 4.0 use-cases
https://plattformindustrie40.at/category/casestudies/	Austrian platform providing Industry 4.0 use-cases
https://www.iiconsortium.org/case-studies/index.htm	American platform providing Industry 4.0 use-cases
https://medium.com/@viarbox/examples-of-industry-4-0-use-cases-728938147570	Article providing Industry 4.0 use-cases
http://usecase.jmfrri.jp/#/en	Japanese platform providing Industry 4.0 use-cases
http://exemples-aif.industrie-dufutur.org/	French platform providing Industry 4.0 use-cases
https://lni40.de/umsetzung/usecases/	Association website providing Industry 4.0 use-cases
https://www.smartindustry.nl/wiki-smart-industry/voorbeelden-van-ondernemers/	Dutch platform providing Industry 4.0 use-cases
https://www.fraunhofer.de/de/forschung/forschungsfelder/produktion-dienstleistung/industrie-4-0.html	Fraunhofer Institut website providing Industry 4.0 use-cases
https://www.iotone.com/	International collection of Industry 4.0 use-cases
https://medium.com/groveventures/mapping-the-israeli-industry-4-0-ecosystem-224f8e350cfa	Platform collecting IIOT startups in Israel
https://medium.com/xangevc/mapping-of-european-industrial-iot-startups-42deca229d80	Platform collecting IIOT startups in Europe
http://dfkoz.com/iot-landscape/	List of IoT startups
https://www.industrie40award.de/	Awarded companies for Industry 4.0 deployment in Germany
http://www.vdma.org/documents/4214230/5356229/Industrie%204.0%20konkret%202016/9912b1a7-be6b-4f32-a132-79aef5b8a11c	Publication on Industry 4.0 use-cases
https://www.bremen-innovativ.de/2018/06/beispiele-digitalisierung/	Collection of innovative Industry 4.0 solutions in Germany
https://amfg.ai/2019/03/28/industry-4-0-7-real-world-examples-of-digital-manufacturing-in-action/	Examples of additive manufacturing deployment in Britain

Study C – Appendix 2. Dendrogram of clustering algorithm



Study C – Appendix 3. Detailed composition of resulting clusters

Cluster	Case ID	Flow object type	Flow object task	Innovation goal for task	System complexity	Organizational scope	Technology
Cluster 1	22	Physical flow	Verification	Enable	Open system	Network	Blockchain
	26	Information flow	Creation	Enable	Open system	Supply chain-oriented	Location sensor technology
	27,63	Information flow	Creation	Enable	Open system	Supply chain-oriented	Smart sensors
	36	Information flow	Creation	Enable	Open system	Supply chain-oriented	Auto-ID
	53	Physical flow	Modification	Enable	Open system	Supply chain-oriented	Smart sensors
	154	Physical flow	Verification	Enable	Open system	Supply chain-oriented	Blockchain

Clu ster	Case ID	Flow object type	Flow object task	Innovation goal for task	System complexity	Organizational scope	Technology
Cluster 2	12	Information flow	Storage	Enable	Controlled system	Intra-firm	Cloud platform
	21	Information flow	Storage	Enable	Controlled system	Network	Platform; software
	24	Information flow	Storage	Enable	Open system	Network	Blockchain
	31	Information flow	Storage	Reduce effort	Closed system	Intra-firm	Smart mobile applications
	33	Information flow	Storage	Enable	Open system	Intra-firm	Cloud platform
	49	Information flow	Storage	Enable	Controlled system	Supply chain-oriented	Platform; software
	60	Information flow	Storage	Enable	Controlled system	Network	Platform; software
	65,66	Information flow	Storage	Enable	Controlled system	Network	DCaaS (Datacenter)
Cluster 3	13,14,15,16,17	Information flow	Transition	Accelerate	Controlled system	Intra-firm	Smart Wearables
	18	Information flow	Transition	Enable	Closed system	Intra-firm	Platform
	19	Information flow	Transition	Enable	Controlled system	Supply chain-oriented	Smart Wearables
	23	Information flow	Transition	Enable	Controlled system	Network	Blockchain
	25	Information flow	Creation	Enable	Controlled system	Intra-firm	Location sensor technology
	29	Information flow	Transition	Automate	Controlled system	Supply chain-oriented	Auto-ID
	32	Information flow	Modification	Automate	Controlled system	Intra-firm	Machine learning algorithms
	34	Information flow	Creation	Automate	Closed system	Intra-firm	Platform; software

Cluster	Case ID	Flow object type	Flow object task	Innovation goal for task	System complexity	Organizational scope	Technology
Cluster 3	38	Information flow	Creation	Automate	Controlled system	Intra-firm	Uncrewed aircraft
	46,51	Information flow	Creation	Enable	Controlled system	Intra-firm	Smart sensors
	52,54	Information flow	Creation	Automate	Controlled system	Intra-firm	Digital Twin
	55	Information flow	Creation	Accelerate	Controlled system	Intra-firm	Digital Twin
	58	Information flow	Creation	Enable	Controlled system	Intra-firm	Auto-ID
	61	Information flow	Transition	Automate	Controlled system	Intra-firm	Platform; Software
	79	Information flow	Transition	Accelerate	Closed system	Intra-firm	Platform; software
	81	Information flow	Transition	Enable	Closed system	Intra-firm	Connected systems
	135	Information flow	Transition	Accelerate	Controlled system	Intra-firm	Machine learning algorithms
	155	Physical flow	Transition	Automate	Controlled system	Supply chain-oriented	Auto-ID
	165	Information flow	Creation	Accelerate	Controlled system	Intra-firm	Smart Wearables
Cluster 4	44	Information flow	Modification	Improve quality	Closed system	Intra-firm	Platform; software
	57	Information flow	Modification	Improve quality	Controlled system	Intra-firm	Digital twin; Machine learning algorithm
	59	Information flow	Modification	Improve quality	Controlled system	Intra-firm	Digital twin; Machine learning algorithm
	67	Information flow	Modification	Improve quality	Controlled system	Intra-firm	Digital twin; Machine learning algorithm

Clu ster	Case ID	Flow object type	Flow object task	Innovation goal for task	System complexity	Organizational scope	Technology
Cluster 4	133	Information flow	Modification	Improve quality	Closed system	Intra-firm	Machine learning algorithm
Cluster 5	9	Physical flow	Modification	Reduce effort	Controlled system	Intra-firm	Collaborating robots
	20	Physical flow	Verification	Automate	Controlled system	Intra-firm	Auto-ID
	28	Financial flow	Modification	Enable	Controlled system	Supply chain-oriented	Information processing infrastructure
	30	Financial flow	Modification	Enable	Controlled system	Supply chain-oriented	Digital twin
	41	Physical flow	Creation	Accelerate	Closed system	Intra-firm	Additive manufacturing
	71	Physical flow	Creation	Enable	Closed system	Intra-firm	Additive manufacturing
	72	Physical flow	Modification	Enable	Controlled system	Intra-firm	Smart machinery
	73	Physical flow	Verification	Improve quality	Closed system	Intra-firm	Digital Twin
	89	Physical flow	Creation	Accelerate	Closed system	Supply chain-oriented	Additive manufacturing
	152	Physical flow	Verification	Accelerate	Controlled system	Supply chain-oriented	Blockchain
	153	Financial flow	Verification	Accelerate	Controlled system	Supply chain-oriented	Blockchain
	162,163	Physical flow	Creation	Automate	Closed system	Intra-firm	Collaborating robots
Cluster 6	3,8,11,64	Physical flow	Storage	Automate	Controlled system	Intra-firm	Autonomous transport systems
	6	Physical flow	Storage	Automate	Controlled system	Intra-firm	Collaborating robots

Clu ster	Case ID	Flow object type	Flow object task	Innovation goal for task	System complexity	Organizational scope	Technology
Cluster 6	7	Physical flow	Storage	Automate	Controlled system	Intra-firm	Smart machinery
	45	Physical flow	Storage	Automate	Controlled system	Intra-firm	Machine learning algorithms
Cluster 7	0,1,2,3,4,50	Physical flow	Transition	Automate	Open system	Supply chain-oriented	Autonomous vehicles
	5	Physical flow	Transition	Automate	Open system	Intra-firm	Autonomous vehicles
	10,39,40	Physical flow	Transition	Accelerate	Open system	Supply chain-oriented	Uncrewed aircraft
	42	Physical flow	Transition	Reduce effort	Open system	Network	Autonomous vehicles
	43	Physical flow	Transition	Reduce effort	Open system	Intra-firm	Autonomous vehicles
	159	Physical flow	Transition	Reduce effort	Open system	Supply chain-oriented	Autonomous vehicles
	175	Legal flow	Transition	Automate	Open system	Network	Blockchain

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