# Internet of Things – the future of managing supply chain risks

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**Abstract**

**Purpose** – The purpose of this paper is to investigate the implications for supply chain risk management (SCRM) by applying internet of things (IoT). Therefore, the impact and effects on the SCRM process, as well as the internal and external pathway and the outcome of SCRM are examined.

**Design/methodology/approach** – This study adopts a multiple case study methodology with twelve companies from the manufacturing industry. This study is guided by the information processing theory (IPT) and a theory-grounded research framework to provide insights into information requirements and information processing capabilities for IoT-supported SCRM.

**Findings** – The studied cases demonstrate an increase in data availability in the companies that contribute to improved process transparency and process management. Furthermore, the process steps, risk transparency, risk knowledge and risk strategies have been enhanced, which enabled improved SCRM performance by fitting information requirements and information processing capabilities, thus allowing for competitive advantage.

**Practical implications** – This study offers in-depth insights for SCRM managers into the structure of IoT systems, primary use cases and changes for the process itself. Furthermore, implications for employees, incentives and barriers are identified, which could be used to redesign SCRM.

**Originality/value** – This study addresses the requirement for additional empirical research on technology-enhanced SCRM, supported by IPT as a theoretical foundation. The radical change of SCRM by IoT is demonstrated while discussing the human role, implications for SCRM strategies and identifying relevant topics for future development.

**Keywords** New technology, Case Studies, Risk Management, RFID Technology, Supply Chain disruptions, Supply risk, Internet of things, IoT, Supply chain risk management, Collaboration, Information processing theory

**Paper type** Case study

## 1. Introduction

Our globalized world relies on the perpetuation of trade flows enabled by complex business environments, which are characterized by enormous pressure, rapid change and high volatility. Therefore, inaccurate evaluations, misjudgments and poor decisions can have considerable consequences for individual companies and the entire supply chain and increase the importance to efficiently manage supply chain risks (Chowdhury and Quaddus, 2016; Colicchia and Strozzi, 2012).

Moreover, in the context of digitization and Industry 4.0, new disruptive technologies influence the development of supply chain management (SCM). Because SCM is influenced by disruptions, an interrelation between digital technologies and SCRM is straightforward (Ivanov *et al.*, 2019). Moreover, the importance of this area is reflected in the practical and scientific interest in technology-enhanced SCRM due to the increasing number of disruptions and far-reaching effects (Schlüter *et al.*, 2017; Dolgui *et al.*, 2018). In addition to technologies such as cyber-physical systems, advanced manufacturing systems, 3D printing or robotics, the smart connection of physical products within the context of IoT is extensively discussed because of its promising improvements such as higher quality at lower costs, rising customer satisfaction or reduced waste (Ben-Daya *et al.*, 2019; Whitmore *et al.*, 2015; Ivanov *et al.*, 2019). This offers the possibility to sense, monitor and interact within a company and its supply chain without the requirement for human interaction (Ashton, 2009; Ben-Daya *et al.*, 2019). Therefore, to positively influence information exchange and transparency to create more flexible supply chains, a high quantity of real-time information can be gathered and processed (Fan and Stevenson, 2018a). However, the high complexity and diversity of influencing factors of IoT lead to an information-intensive SCRM process, resulting in numerous barriers in regard to the organization itself and the supply chain (Birkel and Hartmann, 2019). Moreover, although the importance of the exchange between supply chain partners and the relevance of risk information has been identified, very few studies have focused on the cohesion of information requirements and information processing capabilities in the context of SCRM (Fan *et al.*, 2016; Kilubi and Rogers, 2018). Although individual components such as radio frequency identification (RFID) have existed for some time, price reductions and improved practicability have gradually led to a higher receptivity of companies in maintaining competitiveness (Lee and Lee, 2015). However, despite the strong interest in IoT in SCM, the application in the

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field of SCRM is rather limited and research is hindered by a low number of real-world cases (Ben-Daya *et al.*, 2019; Ivanov *et al.*, 2019). Previously, studies primarily classified and evaluated the influence of novel digital technologies on SCM (Ivanov *et al.*, 2019; Addo-Tenkorang and Helo, 2016), considered theoretical implications for SCRM (Schlüter *et al.*, 2017; Fan and Stevenson, 2018a; Ho *et al.*, 2015; Yang *et al.*, 2013) or focused on individual process steps of SCRM (Scholten *et al.*, 2014; Yan *et al.*, 2017; Fan and Stevenson, 2018b; Kilubi, 2016). There are only a few approaches that holistically examine the SCRM process by incorporating all four stages, the internal and external pathway and the implications for the outcome of SCRM, which includes performance, costs and competitive advantages (Fan and Stevenson, 2018a; Ghadge *et al.*, 2012).

Thus, the aim of this study is to examine IoT in the field of SCRM with regard to the impact:

- the SCRM process;
- the internal and external pathway; and
- the SCRM outcome, which includes SCRM performance.

Because the processing of information to identify, assess, mitigate and monitor disruptions is a key element of SCRM, this study applies information processing theory (IPT) as a theoretical foundation (Galbraith, 1974).

Therefore, to answer the following research question, we conduct a multiple case study with an extensive literature analysis:

*RQ.* How is SCRM, and in particular, the process, the internal and external pathway and the outcome affected by the application of IoT under consideration of IPT?

In reply to this question and to ensure extensive investigation, the remainder of the paper is structured as follows. The next chapter, including the *literature review and theoretical background*, offers a detailed description of all relevant terms and concepts and introduces the theoretical foundation of IPT. Subsequently, the chapter *methodology* presents the case study approach including the sampling, data collection and data analysis. Subsequently, the empirical results are analyzed and discussed to identify patterns and influences while merging literature, theory and case study results. The study closes with a summary, implications for research and practice and limitations.

## 2. Literature review and theoretical background

### 2.1 Supply chain risks and supply chain risk management

Supply chain risks can be specified as follows:

> [...] the likelihood and impact of unexpected macro and/or micro level events or conditions that adversely influence any part of a supply chain leading to operational, tactical, or strategic level failures or irregularities (Ho *et al.*, 2015, p. 5035).

An important aspect of risks in the business context, which is prevalent in risk literature, is the classification as measurable and objective (Ho *et al.*, 2015). The quantitative assessment within the SCRM process allows a numerical calculation of risks as a product of the probability of occurrence and impact (Christopher and Peck, 2004). In conjunction with the complexity of today's supply chains, a number of supply chain risks make it impossible to completely grasp all potential risks (Ho *et al.*, 2015). Furthermore, the quantity and interdependencies of risks considerably depend on the individual network design of the business ecosystem of a supply chain (Varzandeh *et al.*, 2016). Therefore, the importance of the availability of risk-related data to enhance transparency is steadily increasing. Consequently, companies collect and exchange various risk data to provide a reliable basis for decision-making. In addition to data availability, the capability for high process efficiency is imperative (Fan *et al.*, 2016).

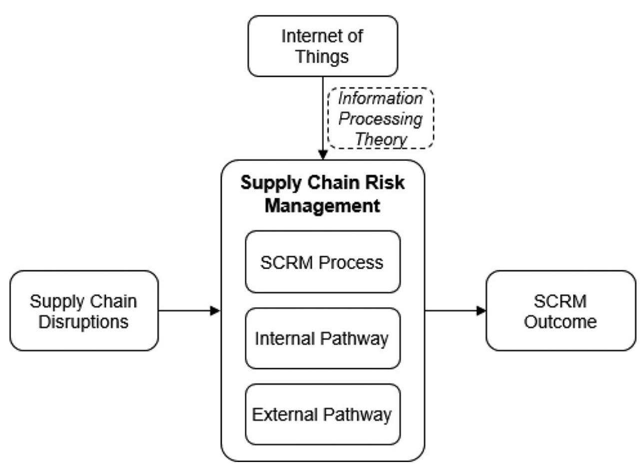
Unlike traditional risk management approaches, SCRM is characterized by a cross-company orientation aimed at identification and reduction of risks along the entire supply chain rather than a restricted intra-company view (Wiengarten *et al.*, 2016). This cross-company orientation is a prerequisite for an effective and successful reaction to the complete spectrum of supply chain disruptions, thus aiming to build the processing capability to reduce vulnerability and ensure business continuity (Fan and Stevenson, 2018a). However, SCRM does not only aim to reduce costs and vulnerability but also requires to ensure profitability and long-term growth (Fan and Stevenson, 2018a). This work follows the definition of Fan and Stevenson (2018a), which captures the whole SCRM process while including the internal and external pathway and its objectives. They define SCRM as follows:

> [...] the identification, assessment, treatment, and monitoring of supply chain risks, with the aid of the internal implementation of tools, techniques, and strategies and of external coordination and collaboration with supply chain members so as to reduce vulnerability and ensure continuity coupled with profitability, leading to competitive advantage (Fan and Stevenson, 2018a, p. 210).

In the following, the individual steps of SCRM process, and internal and external pathway, are briefly explained. They provide the foundation for processing supply chain disruptions and generating SCRM outcomes, which is illustrated in the conceptual framework (Figure 1).

The first step of SCRM process is called *risk identification*. Its key task is to discover all relevant risks along the supply chain and its sources to improve visibility and to reveal possible future uncertainties for proactive management (Hoffmann *et al.*, 2013). This process step is of great importance, as countermeasures can only be applied if a risk has been identified

**Figure 1** Conceptual framework for SCRM



(Fan and Stevenson, 2018a). In addition, both insufficient visibility and delayed information adversely influence the ability to make accurate analyses and decisions, even for already identified risks (Khan and Zsidisin, 2012).

The second step, *risk assessment*, combines the evaluation of all identified risks according to their probability of occurrence and their negative impact on the supply chain's performance (Hoffmann *et al.*, 2013). The quantitative assessment supports the prioritization of risks and forms the foundation for further action such as selecting a treatment strategy (Blome and Schoenherr, 2011). This process step faces the challenge of being comprehensive, fast and cost-efficient at the same time. To meet these requirements, a standardized process is proposed in the literature, which could contain formal and informal components (Zsidisin *et al.*, 2004). Moreover, to holistically assess risks, both quantitative and qualitative data should be used (Zsidisin *et al.*, 2004). An improvement in assessing risk probabilities and their impact is achieved by an extensive exchange of information and thus a low information asymmetry between supply chain stakeholders (Li *et al.*, 2015). Because data exchange is a core functionality of IoT, this indicates a positive influence by its application (Figure 1).

The aim of the third step, called *risk treatment*, is converting conceptual evaluations into application-based measures. Similar to risk assessment, the balance between efficiency and effectiveness must be considered when selecting appropriate treatment strategies (Heckmann *et al.*, 2015; Wiengarten *et al.*, 2016). Because multiple strategies need to be selected, they should be continuously verified for minimum contradiction and potential synergies (Braunscheidel and Suresh, 2009; Ho *et al.*, 2015).

The literature differentiates between five generic risk treatment types: risk acceptance, avoidance, transfer, sharing and mitigation, while studies focus on risk mitigation (Fan and Stevenson, 2018a). The various treatment strategies are suitable for diverse risk cases, which are characterized by combining both high or low probability and impact. However, generalizing treatment types is difficult because each case must be individually considered, which in turn, increases the SCRM's complexity (Fan and Stevenson, 2018a). Risk treatment can be further classified as either proactive or reactive (Kırılmaz and Erol, 2017; Kilubi, 2016). Proactive strategies involve actions are implemented to diminish risks before they occur. The approaches include the decrease of either the probability or the impact of the risky event in advance such as contractual agreements, increasing visibility or supplier development (Tukamuhabwa *et al.*, 2017). Moreover, reactive strategies can be included in advance, but they only mitigate the impact after disruption occurs (Kırılmaz and Erol, 2017). The examples are contingency re-routing, creating redundancy or increasing velocity (Tukamuhabwa *et al.*, 2017; Kilubi, 2016).

*Risk monitoring* deals with the continuous review of identified risks to examine current measures and realign them. As within risk identification, a standardized process is recommended for support. Despite the considerable importance of this process step, risk monitoring is often neglected in both theory and practice (Hoffmann *et al.*, 2013; Fan and Stevenson, 2018a).

In addition to the risk process, both internal and external pathways inherit a decisive role in SCRM.

The internal pathway includes two aspects: the selection and implementation of SCRM strategies and the human factor. Table I shows the main proactive and reactive strategies for SCRM discussed in the literature and demonstrates the importance of visibility and transparency via intensive cooperation and data exchange (Kilubi, 2016). A further common strategy to reduce uncertainty in the supply chain is to build up redundancies via higher inventories. However, to be secured and cost-effective, the balance between proactive and reactive measures is crucial. The second aspect of the internal pathway is the human factor. Because of the high complexity of SCRM, completely automated processing is difficult to accomplish. Therefore, decisions are often based on the experience of senior employees, thus highlighting them as an essential information source and decision-maker in SCRM (Kırılmaz and Erol, 2017). Furthermore, the emergence of disruptive technologies indicates a change in the role and responsibilities of employees (Ivanov *et al.*, 2019).

The external pathway includes external coordination and collaboration with partners. In the supply chain literature, the importance of continuous dialogue and information exchange with supply chain partners is omnipresent (Ho *et al.*, 2015; Fan *et al.*, 2017) and is reflected as a key element for strategies. In particular, information and communication technologies have fostered the exchange of information (Aryal *et al.*, 2018). Because the technological alignment of supply chain partners is a prerequisite for the successful implementation of technologies (Wang *et al.*, 2016), a further improvement in cooperation by implementing IoT is anticipated because it represents an advanced level by the holistic linking of physical devices and the generation of information in real-time (Aryal *et al.*, 2018). Furthermore, the specification of collaboration with partners is of considerable importance because it determines, for example, the number of suppliers for product components and thus has a significant influence on the balance of SCRM (Kilubi, 2016).

### 2.2 Internet of Things

The term IoT was introduced by Kevin Ashton in 1999 and describes the interconnection of computing devices embedded in physical objects to gather and save information without the requirement for human interaction (Ashton, 2009; Ben-Daya *et al.*, 2019). IoT can be defined as follows:

> [...] a network of physical objects that are digitally connected to sense, monitor and interact within a company and between the company and its supply chain enabling agility, visibility, tracking and information sharing to facilitate timely planning, control and coordination of the supply chain processes (Ben-Daya *et al.*, 2019, p. 4721).

Today's concept of IoT does not limit itself to the use of RFID because it integrates further technologies such as near field communication, wireless sensors, actuators or smart items (Atzori *et al.*, 2010). According to Xu *et al.* (2014), the IoT

**Table I** Proactive and reactive SCRM strategies

| Proactive strategies | Reactive strategies |
|---|---|
| **Visibility and transparency** | Visibility and transparency |
| **Partnerships/relationships** | Redundancy (inventory) |
| **Redundancy (inventory)** | Flexibility |
| **Joint planning and coordination** | Multiple sourcing |
| | Postponement |

**Source**: Adapted from Kilubi (2016)

network includes four essential layers: the *sensing layer*, which integrates existing hardware to sense the physical world and acquires data; the *networking layer*, which connects and transfers data over wireless or wired networks; (3) the *service layer*, which integrates and manages services and applications through middleware; and (4) the *interface layer*, which displays information and allows the user to interact with the system. This enables IoT to capture a large amount of data (Big Data) and process it by implementing services and applications. Furthermore, the scalability of these systems possesses high potential by an easy integration of additional sensors or external data (Xu *et al.*, 2014). In addition to the increasing size, data can be captured faster from variable sources. Literature characterizes these properties of Big Data, including volume, variety and velocity, as the triple "V" baseline (Arunachalam *et al.*, 2018).

Furthermore, IoT offers the potential to gather positions, temperatures, shocks and additional parameters to increase data exchange, agility and visibility, resulting in a higher level of transparency (Miorandi *et al.*, 2012). By collecting, generating, processing and exchanging data via mobile applications or information systems, which are located in data centers or clouds, these aspects indicate an improvement for SCRM terms of both data availability and process management (Whitmore *et al.*, 2015; Ben-Daya *et al.*, 2019).

### 2.3 Information processing theory in the context of supply chain risk management

To better understand how IoT is changing SCRM, IPT is applied as a theoretical foundation. IPT is an extensively used theoretical perspective and has been adopted in various fields such as information systems or decision science (Fan *et al.*, 2016). This theoretical perspective considers firms as information processing systems, which help to cope with uncertainty because of disruptions (Tushman and Nadler, 1978; Fan *et al.*, 2016), while the organizational activities are regarded "in terms of information that must be gathered, interpreted, synthesized, and coordinated in the context of decision making" (Burns and Wholey, 1993, p. 110). Therefore, the successful operation of a company's processes is not based on a simple response to stimuli but on effective and efficient processing and interpretation of information (Miller, 1956). Both optimal task efficiency and performance are achieved by the fit between the *information processing needs* and the *information processing capabilities* and require the coordination of structures, processes and information technologies (Galbraith, 1977).

Fan *et al.* (2016) outline three aspects, which describe the core notion of IPT in the context of the effectiveness of SCRM. First, with increasing uncertainty of tasks of a company, decision-makers are required to process a greater amount of information during the task execution to achieve the desired performance (Galbraith, 1973). Second, to effectively process a considerable amount of information, the firm needs appropriate information processing capabilities. This describes the ability to collect, disseminate and synthesize information to deal with uncertainties (Tushman and Nadler, 1978). Third, to achieve superior performance, there should be a fit between the requirements and capabilities of information processing (Galbraith, 1973). Because SCRM deals with coping uncertainties arising from supply chain disruptions to achieve consistent or superior SCRM performance (Fan and Stevenson, 2018a), the synthesis of the core aspects of the IPT supports our research endeavor to understand how implementing IoT affects SCRM.

Furthermore, in the literature, two main strategies are proposed to solve the problem of uncertainty. On the one hand, the need for information can be reduced. This is achieved by buffering strategies such as high safety stocks or multiple suppliers (Kauppi *et al.*, 2016). However, these strategies are very resource-intensive and in today's competitive business environment are not cost-effective. On the other hand, information processing capabilities can be enhanced to gain better control over operational activities (Kauppi *et al.*, 2016). These capabilities can be divided into information sharing and information analysis (Fan *et al.*, 2016). Information sharing refers to the extent of jointly shared critical or proprietary information (Fan *et al.*, 2016), which is crucial for supply chain visibility (Christopher and Lee, 2004) and acts as an enabler for supply chain mitigation (Chopra and Sodhi, 2014). It is especially important across company boundaries and includes coordination and collaboration with suppliers and customers (Schoenherr and Swink, 2012). The information analysis comprises using tools to transform shared data into useful information and guide decision-making (Fan *et al.*, 2016).

Based on the availability of real-time information (Aryal *et al.*, 2018), enhanced information processing (Ben-Daya *et al.*, 2019) and support of decision making (Ivanov *et al.*, 2019), the implementation of IoT influences the SCRM process and the internal and external pathway. Consequently, a holistic consideration is crucial, which is highlighted in the literature (Fan and Stevenson, 2018a, 2018b). Therefore, Figure 1 shows the influence of IoT on SCRM as a conceptual framework, which serves as the foundation for the conducted case study.

## 3. Methodology

### 3.1 Research design

The synthesis of academic literature dealing with the potentials and implications of IoT demonstrates that the actual discussion predominantly focuses on the influence on SCM, theoretical implications for SCRM or individual process steps of SCRM. Research focusing on the SCRM environment, the SCRM process or the SCRM outcomes is limited, while the scarce practical studies primarily focus on the food or healthcare supply chain (Yan *et al.*, 2017; Aryal *et al.*, 2018). To address our research question, we conducted a multiple case study. We selected this approach for several reasons. According to Yin (2014, p. 16):

> [...] a case study is an empirical inquiry that investigates a contemporary phenomenon (the 'case') in-depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident.

Because of its interactive characteristics, case research is ideal for investigating complex phenomena and its numerous influencing factors as in the case of IoT in SCRM (Voss *et al.*, 2002; Yin, 2014). Second, this research design fits our aim to understand how IoT is used among firms and how it influences the SCRM process. Furthermore, the multiple case approach, compared to the single case approach, produces results that are better grounded and more accurate and therefore increase the generalizability of the results. Correspondingly, a grounded

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theory methodology was applied, which allows the exploration and organization of raw empirical data and its subsequent transformation into a theoretical schema (Corbin and Strauss, 1990).

To ensure high-quality results that qualify for theory building, the four criteria *construct validity, internal validity, external validity* and *reliability*, as shown in Table II, have to be fulfilled during the execution of this case study.

### 3.2 Sampling

The key literature on case study research attributes a crucial function to the selection of cases because it defines the set of entities from which theory-building takes place (Eisenhardt, 1989). Furthermore, to guarantee the generalizability of the study results, the case study method attaches considerable importance to a representative selection of cases. Consequently, we developed a comprehensible sampling logic at the very beginning to identify qualified interview participants. The criteria ensure comparability between all cases. Within this study, all cases have been selected based on the following criteria.

First, the target group was limited to the manufacturing industry because they manage supply chains with physical products. For these products, the process of SCRM is of particular importance because the material flow has considerable influence on the complexity of the company's operations and their consequences such as sourcing, supplier selection, supply product quality and customer satisfaction (Tang and Musa, 2011). Second, the manufacturing and selling activities of all participants primarily had to be located in Europe because this constraint guaranteed that all companies within the research group faced similar prerequisites such as infrastructural, legal and political. Third, to secure factual and first-hand insights, companies had to prove their digital capabilities by implementing IoT technology in their supply chain processes. Fourth, to examine the full potential of IoT in SCRM, it was required that the companies had internationally operating activities with an intermodal and globally linked supply chain. Moreover, both end-product manufacturers, and suppliers operating in the business-to-business (B2B) and business-to-consumer (B2C) environment were involved. Based on these criteria, online desk research was conducted to identify suitable companies.

In relation to determining the optimal number of samples for a multiple case study, the literature provides several recommendations. While Eisenhardt (1989) proposed four to ten cases to be sufficient, other authors state that a maximum of 15 cases should not be exceeded (Goettfert, 2015; Perry, 1998). Following the approach of Corbin and Strauss (1990), additional cases were included until saturation was reached because any further cases would have only provided marginally new insights, little variation compared to the collected data and no relevant implications for our research endeavor. The final sample includes 12 companies, which are summarized in Table III. Based on the anonymization guidelines, the numbers of employees and the revenue are displayed via an incremental range; moreover, the sectors portray a rough outline of the companies' spheres of action. In addition to business focus, the competence areas of the interviewees are presented.

### 3.3 Data collection

During the data collection process, several sources of evidence have been used in which the interviews with industry experts served as the primary and most valuable data source (Yin, 2014). The interviews were conducted with department heads and experts from SCM and adjacent departments such as procurement or production planning. Special emphasis was placed on the connection to the areas of risk management and digitization, which secured the collection of relevant information (Table III). To ensure high construct validity and to allow for triangulation, we enriched the interview

**Table II** Validity and reliability issues addressed throughout the research phases

| Criterion | Research phase<br>Research design | Case selection | Data collection | Data analysis |
|---|---|---|---|---|
| **Construct validity** | Use and adaption of questionnaire based on extensive review of literature | n/a | Collection of multiple data sources<br>Multiple interviewees within several cases of analysis until saturation was reached | Review of interviews protocols by participants to eliminate misunderstandings and ambiguities |
| **Internal validity** | Analysis and synthesis of existing literature of IoT and SCRM | n/a | Variety of informants | Pattern matching and addressing of rival explanations through cross-case analysis<br>Triangulation of multiple data sources<br>Research team discussions |
| **External validity** | Conduction of multiple case study | Explicit description of case firms and context | n/a | Analytical generalization based on industry specifics |
| **Reliability** | Development of case study protocol | Selection based on predefined search strings and criteria | Shared questionnaire for all interviewees<br>Development and utilization of case study database | Support of a third researcher who was not involved in the data collection process |

**Source**: Adapted from Yin (2014) and Gibbert *et al.* (2008)

**Table III** Overview of interviewed companies

| Case Name | Job title of contact person | Company Sector | Business focus | Number of employees[a] | Revenue[b] |
|---|---|---|---|---|---|
| ***Alpha*** | Coordinator of logistics 4.0 projects in SCM<br>Supply chain risk manager<br>Data analytics manager in SCM | Automotive supply, building technology & electronics | B2B/B2C | >50,000 | >50 billion EUR |
| ***Beta*** | Strategy expert of digitalization and predictive analytics<br>Strategy expert of digitalization and predictive analytics | Electronics, building technology, healthcare, energy management | B2B | >50,000 | >50 billion EUR |
| ***Gamma*** | Coordinator of program processing<br>Logistics structural management | Commercial vehicles | B2B | 25,000 - 50,000 | 10 billion EUR – 50 billion EUR |
| ***Delta*** | Supply chain manager<br>Head of operative logistics | Automotive | B2B/B2C | <25,000 | <10 billion EUR |
| ***Epsilon*** | Group vice president supply chain<br>Supplier development and supply chain risk manager | Measurement technology | B2B | <25,000 | <10 billion EUR |
| ***Zeta*** | Innovation manager for supply chain and simulation | Automotive | B2C | >50,000 | >50 billion EUR |
| ***Eta*** | Head of SCM and transport planning | Automotive supply | B2B | <25,000 | 10 billion EUR – 50 billion EUR |
| ***Theta*** | Head of procurement and industry 4.0 | Aerospace | B2B | <25,000 | <10 billion EUR |
| ***Iota*** | Principal engineer at global research department | Electronics & chemistry | B2B | >50,000 | >50 billion EUR |
| ***Kappa*** | Head of corporate logistics (strategy & standards) | Automotive & engineering | B2B | >50,000 | 10 billion EUR – 50 billion EUR |
| ***Lambda*** | Head of digital supply chain department | Electronics | B2B | 25,000 - 50,000 | <10 billion EUR |
| ***My*** | Director of planning and production | Consumer goods | B2C | >50,000 | 10 billion EUR – 50 billion EUR |

**Notes:** [a] Range of number of employees: <25,000; 25,000 – 50,000; >50,000; [b] Range for revenue: <10 billion EUR; 10 billion EUR – 50 billion EUR; >50 billion EUR

information with secondary data such as corporate publications, publicly available documents and company websites. In addition, additional secondary data, such as newspaper articles and annual reports, were collected to retrospectively validate the results. The interview questionnaire was then developed from an extensive literature review and discussions within our research team and followed a semi-structured design such as open questions. Subsequently, the questionnaire was discussed and further developed with academics researching the field of IoT and SCRM. The semi-structured design was adopted because of its beneficial flexibility, i.e. its ability to interact with each participant differently while still addressing the same areas of data collection (Yin, 2014). Potential fuzziness or misunderstandings within the questionnaire were corrected with experience obtained from two interviews with industrial experts, which were conducted prior to the official study.

In total, 18 interviews were conducted in the period between mid-2017 and the beginning of 2018, including the interviewees' feedback. The interviews were conducted via telephone, lasted between 50 and 75 min and were recorded to enable re-listening and transcription. In addition, during the interviews, we independently took notes, which were discussed and synthesized afterward. Each participant received a copy of the transcript to reassure the correctness of the information and avoid misunderstandings and ambiguities (Yin, 2014). The revised protocols and all information from the secondary sources were used to build the basis of the case study database and support reliability (Gibbert *et al.*, 2008).

### 3.4 Data analysis

Following the coding process developed by Corbin and Strauss (1990), open coding was applied to analytically cluster the unstructured information within each interview, interconnect them and identify core categories using an iterative process. First, the confirmed transcripts of each interview were analyzed to separate obviously irrelevant and possibly significant content. Aggregating the data, such as interview quotes and notes, to superior categories enabled the identification of structures, patterns and relationships (Corbin and Strauss, 1990). For this purpose, all relevant statements were paraphrased and assigned to categories with different thematic references and levels. The first level comprised facts, which objectively assess and define statements' content. The fact codes, in turn, were converted into thematic codes to determine and bundle findings. This process was reiterated for each interview while the categories were adjusted gradually. Furthermore, secondary data were integrated to reduce bias and verify the statements. As the same categories were used for all interview transcripts, this process enables efficient comparison of the different case companies (Blumberg *et al.*, 2014). While conducting the coding, because of the open questions, we focused on discussing and relating statements from seemingly independent questions. To support the categorization of the data, a computer-aided qualitative data analysis software was used because it is recommended for facilitating the handling of large amounts of data and as guidance during the iterative coding and categorization procedure (Yin, 2014). Because investigator bias could present an issue and to ensure reliability, the coding was individually created. Deviating results with regard to interpreting the expert statement, allocation to categories and wording were gradually approximated in detailed discussions within several research meetings until an agreement was reached. This iterative approach ensured inter-rater reliability and the high quality of our analysis (Pagell and Krause, 2005).

Finally, after our conceptual framework for SCRM, the further data analysis section contains a cross-company analysis to identify similarities and differences among the single units of analysis to derive the effects on SCRM (Eisenhardt, 1989).

## 4. Analysis

### 4.1 Structure of Internet of Things systems

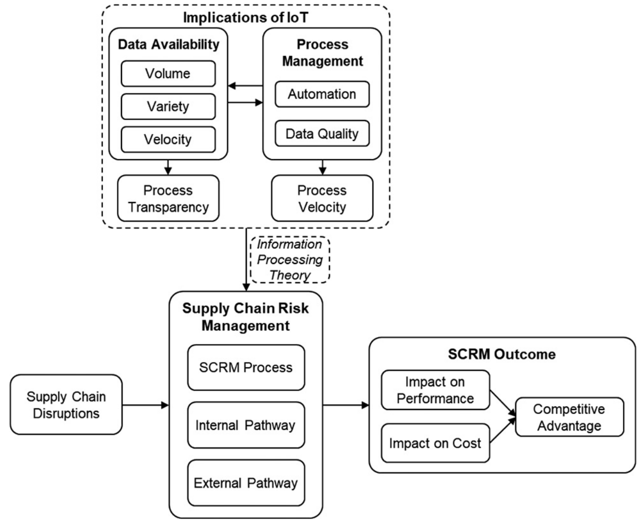
Before analyzing how SCRM is affected by IoT implementation, an overview of the structure of the investigated IoT systems is offered to provide transparency with regard to the often rather vague term IoT.

IoT systems are then divided according to the individual layers. In the sensing layer, the RFID, global positioning system (GPS) and sensors could be identified, which in all cases were wirelessly linked to each other. While RFID was used for every application, the types of sensors differed. The majority of companies installed sensors to capture temperatures, air pressures and vibrations, while optical and humidity sensors were used in few exceptions. The service and interface layer contains both external and internal services and applications. In seven of the twelve companies, the software was developed in-house; in four further cases, internal development was accompanied by an external expertise. The high number of self-developed applications indicates the early stage of technology development and highlights the requirement for further advancements. The input for processing information in the service layer can either be internal, such as a company's own supplier rankings, correspondence or self-identified risks, or external, such as messages or machine data from suppliers. In most cases, a combination of internal and external data input was selected, which emphasizes the necessity of successful data exchange.

### 4.2 Impact of the Internet of Things on supply chain risk management

In addition to the practical insights into the structure of IoT systems, the core of a case research study is the research framework (Voss *et al.*, 2002). To answer the research question and guide our work, we enhanced our theory-based research framework, as illustrated in Figure 2. The individual aspects of the framework and its effects are discussed below, supported by the results of our case study.

**Figure 2** Research framework




#### 4.2.1 Implications of Internet of Things

SCRM is initially influenced by the implications of IoT, which are divided into *data availability* and *process management*. Data availability is further subdivided into volume, variety and velocity. This is derived from the function of IoT as an accelerator of the 3Vs of Big Data and is widely accepted in literature and practice (Arunachalam *et al.*, 2018). The case analysis confirms this circumstance. While Alpha, Zeta and Lambda reported that the use of IoT is generating more data within their company, especially in production, companies such as Delta, Iota and Epsilon mentioned beyond that an expansion of knowledge of external risks. Therefore, not only does the amount of data increases but the range of information sources also expands. In addition to the increase of the volume of real-time information, Epsilon mentioned the improved speed in information gathering and the multidimensional complexity of the data, which can be collected by IoT. The improved data availability further increases process transparency because real-time temperature curves of a container transport can be transmitted.

*P1.* The implementation of IoT increases the volume of data, the variety of possible sources and the velocity of data gathering for managing supply chain risks, resulting in superior risk process transparency and reflects an improved information gathering in line with the IPT.

In addition to data availability, the capability to process data is crucial, which is stated in IPT. For this reason, process management comprises *automation* and *data quality*, which influence *process velocity*. Higher automation, as one of the core applications, in combination with higher data quality, which stands in contrast to the pure quantity of the data available, leads to an improved process velocity. Altogether using real-time data and increase in velocity was mentioned by almost all case companies; however, they reported the improved information processing capabilities of algorithms and software tools compared to human actions.

*P2*. The implementation of IoT improves the level of risk process automation and data quality, enabling more reliable risk process management with a higher velocity and thus reflects an improved information analysis in line with IPT.

*4.2.2 Impact on the supply chain risk management process steps*

*4.2.2.1 Risk identification.* As revealed by our cross-case analysis, IoT has the potential to modify and improve risk identification within supply chains on several layers. It is considered to be one of the most important steps in SCRM, creating the prerequisite for further steps (Ho *et al.*, 2015; Ben-Daya *et al.*, 2019; Fan and Stevenson, 2018a). This is consistent with the high number of risk identification-related statements in our case study, which reflects the importance of IoT and its primary application, i.e. tracking and tracing. All case companies predominantly stated that the majority of the currently offered tracking possibilities do not offer follow-up in real-time. Similar to courier services, only nodal points (e.g. arrival at the port, loading at the hub) are observable for SCRM. For this reason, the companies tend to initiate their own tracking and tracing projects, primarily for valuable or pernicious goods. The data collection of locations and conditions allows the continuous comparison of current and desired states for the identification of deviating parameters to achieve real-time transparency. In this context, the greatest potential arises for long-distance transport modes with time-consuming journeys.

Furthermore, the experts highlighted that risk identification will be especially improved by the high scalability of IoT and easy integration of devices into its network. Because of the necessity of pre-defined and quantifiable target values, automated risk identification is particularly suitable for micro risks with a rather high probability and low influence. These risks are primarily addressed via a mitigation strategy, which is the focus of theory and practice (Fan and Stevenson, 2018a) and therefore emphasizes the importance of the field of application of IoT in SCRM.

*P3*. The enhancements in risk process transparency and velocity by applying IoT improves the identification of risks and is particularly suitable for identifying micro risks, which are characterized by a high probability of occurrence and a rather small impact.

*4.2.2.2 Risk assessment.* Based on the data of risk identification, the following process step aims at the assessment. Because risks can be described by the probability and the impact of events, these factors are in focus during the analysis and assessment of risks. First, IoT leads to generating high availability of risk-related data that was previously manually processed and evaluated with qualitative methods, resulting in vague probabilities and impact analyses as described by the participants. These methods will be gradually replaced by more reliable standardized quantitative methods, enabled by the rising dissemination of embedded sensors and actuators and the integration of further services. Therefore, automated quantitative methods such as mathematical programming via algorithms, stochastics or metaheuristics can be adapted for the data interpretation. In addition, the interview sample revealed a consistent trend towards the development of analytical solutions for the intelligent processing of IoT data, harmonizing information requirements and information processing capabilities. However, the adoption of quantitative methods, mostly relying on objective data, turned out to be of little use in practice among the companies interviewed. Instead, even large companies, such as Iota or My, still predominantly used subjective assessment supported by objective data. Furthermore, the participants mentioned limitations of the risk assessment, such as the high complexity of risk inter-relationships, highlighted in the literature (Fan and Stevenson, 2018a, 2018b).

Nevertheless, the extensive data pool and the integration of quantitative data analyses indicate an improvement in risk assessment. The consensus of the participating companies indicates that, in the near future, only exceptional cases will trigger an alert, which will be processed manually by experts. Epsilon, Theta and Lambda explicitly stated that the risk assessment will, however, never completely rely on algorithms; in fact, further experts will be needed to support the process conversion as stated the strategy experts of Beta:

> You have to be able to rely on facts. [...] An objective assessment can only be made based on reliable data and verifiable figures. However, there will always be a 'gut feeling', as there are always exceptions that cannot be planned in.

This is consistent with the literature because Tsai *et al.* (2008) concluded that combing subjective perception and objective data might result in a more robust risk construction and therefore will improve the risk prediction and assessment.

*P4*. The enhancement in the risk identification through the application of IoT improves the assessment of risks through a higher level of process automation, increasing application of standardized quantitative methods and intelligent processing of data in SCRM supported through risk experts.

*4.2.2.3 Risk treatment.* As the companies pointed out, IoT's positive influence in the risk identification phase directly affects the subsequent SCRM phases, especially risk assessment and risk treatment. With regard to the various risk treatment strategies, the companies focused on risk mitigation, which receives the highest consideration in the literature (Fan and Stevenson, 2018a). This is not surprising because IoT can enable quick and established decision-making with the help of real-time data to avoid disruptions and reduce the damage of events. Therefore, risk mitigation is the most promising use case.

The participating companies assigned IoT different emphasis regarding the proactive and reactive risk mitigation strategies. While Alpha, Epsilon, Zeta, Iota and Kappa predicted a shift from reactive risk mitigation strategies to strategies with a more proactive character, Delta, Lambda and My stated that many risks cannot be identified in advance, and therefore limit proactive handling. They warned against solely focusing on proactive strategies because all risks, which are not prematurely spotted, still require reactive counter-measures.

According to Beta, Gamma, Epsilon, Eta and Iota, proactive actions will result in fewer disruptive events that could possibly harm the supply chain's performance, while Delta denied a reduction as risks currently are no longer preventable. Moreover, My highlighted that the increasing number of proactive approaches will not necessarily produce better results because of high costs and the fact that the executions of mitigation strategies are not compulsory. However, although the influence on the number of disruptions seems uncertain, the consensus between all participants was that the amount of damage may decrease. This was justified by better precaution times and faster counteractions. Thus, we conclude that an unambiguous shift to either the proactive or reactive risk treatment cannot be identified, but rather an intensification of both approaches. To conclude, IoT equally influences the measures of mitigation strategies such as knowledge management, supplier development or adaptation of the supply network and the flexibility or visibility. However, faster identification and assessment do not automatically result in faster risk mitigation as stated by Alpha. Instead, the processes have to be realigned to speed up mitigation, which is neglected in the literature.

*P5.* The application of IoT supports the management of supply chain risks through better precaution times and faster counteractions and enhances proactive and reactive strategies that are applied for risk mitigation.

*4.2.2.4 Risk monitoring.* Even if risk monitoring receives little attention, it is of considerable importance (Hoffmann *et al.*, 2013). Risks are not static but require continuous monitoring supported by formal processes and judgmental assessments (Zsidisin, 2003). In line with the findings of Fan and Stevenson (2018a), it was revealed that the participating companies did not consider risk monitoring as an independent step. Instead, it is merged with the other steps, especially risk assessment. This is in line with Blackhurst *et al.* (2008), which examine similar industries in their study. The results from risk identification and risk mitigation, but in particular from the assessment phase, can be transferred to risk monitoring. IoT could, therefore, have a positive influence because of its higher transparency, fast and automatable processes and robust analyses. Additionally, it offers an excellent opportunity to support pre-SCRM (analysis of the supply chains) and post-SCRM (continuous improvement), which require more attention in research (Ho *et al.*, 2015).

*P6.* The improvement of the preceding risk process steps by applying IoT indicates an advanced monitoring of risks, which is treated as a subordinated process step in all cases and therefore reveals great research potential.

*4.2.3 Impact on the internal pathway*

In addition to individual process steps, IoT implementation influences the internal pathway, comprising the selection and implementation of SCRM strategies and human factor. However, the selection of strategies depends on various aspects. First, there is a positive link between the implementation of IoT and risk transparency. This is attributable to the combination of the higher and faster availability of data and improved process management, enabled by automation and optimization with reliable data quality. The increasing risk transparency was emphasized by all case companies in various statements and is consistent with appraisal in the academic literature (Fan and Stevenson, 2018a). Even if all cases agreed to the extension of transparency within their own organization and the logistics operations, they questioned whether visibility regarding the *n*-tier network will rise. This doubt is based on their experience that their suppliers are not willing to share information about their own suppliers. The existing literature reflects this, because it does not distinguish between transparency in the near and far environment.

Furthermore, the analysis of the interviews indicates a positive effect of risk transparency on risk knowledge. Enhanced risk knowledge benefits from the continuous verifiability of processes and risks facilitated by real-time data but also from the collection and storage of data. This enables retrospective screening and analysis of historical data to identify patterns and conditions, e.g. knock-on effects or risk inter-relationships, which have led to disruptions in the past. Thus, not only can current data be processed for assessment but the entire risk knowledge can be improved, supporting risk prioritization. To our astonishment, however, only half of the companies explicitly mentioned the retrospective analysis of data. In this context, we anticipate great potential for improvement, although the executed approaches by the participating companies were in their infancies.

The positive influence on risk knowledge and risk prioritization are key issues for selecting a treatment strategy. As stated in the literature, the participating companies focused their use of IoT on risk mitigation strategies. As we could derive from our interviews, IoT fosters optimized mitigation strategies because it allows for faster reactions and increased flexibility. The enhanced risk knowledge aggregates all relevant information to customize and design mitigations strategies in more detail. Therefore, IoT allows improving both proactive and reactive strategies, such as visibility and transparency, which in turn can facilitate flexibility. The enhanced exchange of information can foster partnership with suppliers, supported by technological alignment and partnership commitment. These relations confirm the positive impact of IoT on both types of strategies, as stated in proposition 5.

*P7.* The application of IoT favors higher risk transparency, improved risk knowledge and risk strategies, facilitated by increasing data availability and enhanced risk process management.

Even if all case companies agree on a higher degree of automation, they stated that algorithms could not totally replace human supply chain risk managers. This outcome is supported by the statements of Beta and Delta who highlighted the complex interdependencies between different supply chain stakeholders and risks, which require human judgment and therefore limit automation and the reaction to non-standardized events. However, this leads to a change in job profiles towards more strategic tasks and will therefore affect other aspects such as the SCRM culture or team relations. In terms of risk mitigation, human actions can be reduced to controlling and correcting activities, which is beneficial in reducing risks through reduced human errors and shorter reaction times. Because of insecurity and change, the acceptance of new technologies is a barrier that can only be overcome by involving all employees early in the development and implementation of the system (Barton and Court, 2012).

*P8.* The enhancements of the individual stages of the SCRM process allow standardized risks to be processed without human intervention, although exceptional cases continue to require human judgment through the complex interdependencies of stakeholders and risks.

*4.2.4 Impact on the external pathway*

Suppliers are vital for the success of a company because they deliver key elements in business while being a potential source of risks. The high complexity and competitiveness of the prevailing supply chain networks and the dependence on suppliers increase the importance of a careful choice of supply chain partners and stress the relation to SCRM (Giunipero and Eltantawy, 2004). In the course of our investigations, the interviewees put great emphasis on the improvements in selecting suppliers because of IoT-related applications. This is highlighted in the literature because the technological alignment has been a major factor in selecting supply chain partners (Wang *et al.*, 2016). Furthermore, the participants stated reduced effort towards audits and supplier evaluation because of the available vendor transparency. Thus, the complex and expensive audit procedure could be optimized by applying IoT. This leads to a reduction in transaction costs and a decreasing replenishment time for alternative sourcing and supplier selection. Therefore, the transition between different suppliers and between a single or multiple sourcing strategy becomes more flexible, although it facilitated the possibility of continuous audits. This reduces further risks such as the suppliers' dependency and opportunism. In line with the improved risk strategies, rising flexibility could be observed in the majority of cases, independent of the supply chain stage. Because of these improvements, two of the participating companies decided to focus on a single sourcing strategy. Even if this strategy leads to a higher dependency, the application of IoT allowed a superior selection of suppliers, leading to reduced risks at lower costs. The other companies confirmed these advantages.

*P9.* The application of IoT enables continuous audits and supplier evaluation through a higher level of risk transparency and facilitates supplier selection and the flexibility of sourcing strategies.

*4.2.5 Impact on the supply chain risk management outcome*

In the last part of our framework, the implications for the SCRM outcome are presented, comprising effects on performance, costs and a competitive advantage. Summarizing the positive influence of IoT on the SCRM process and the internal and external pathway, we conclude a positive effect on SCRM performance. This is primarily attributed to the possibility of realizing the fit between increased information needs and information processing capabilities, which has been highlighted by improved information availability and process management. These improvements in dealing with uncertainties because of supply chain disruptions have been confirmed by all companies, despite the application of different risk strategies. In addition to the improvement in SCRM performance, cost benefits could be observed. These were primarily attributed to declining inventories enabled by greater transparency and flexibility in the context of supplier-related transaction costs. Although investments are required for implementing IoT, the long-term application indicated that the advantages outweighed the costs. The combination of these two effects suggests that the implementation of IoT can not only lead to an increase in performance but can also reduce costs and thus may lead to a competitive advantage.

*P10.* The application of IoT can be characterized by an improved SCRM performance and overall cost reductions for managing risks, which are likely to result in a competitive advantage.

## 5. Discussion

In the previous sections, we presented the implications of IoT on the individual risk process steps, the internal and external pathway and the risk outcomes, based on the IPT and supported by multiple in-depth cases. To answer comprehensively our research question, we would like to highlight some important research areas and discuss them in the following.

### 5.1 Development of supply chain risk management through the application of Internet of Things

Our findings indicate the sustainable impact of IoT on the future execution of SCRM while addressing the needs for an information technology platform for intensive and fast sharing of risk-related information. The positive influence of IoT on data availability and information processing capabilities for the advanced management of risks by applying self-acting algorithms for operational risks and the provision of information on strategic risks is illustrated. These results agree with those in the literature and represent an innovative field of research because of the application of IoT in the area of SCRM supported by the theoretical foundation of the IPT (Fan *et al.*, 2016; Ben-Daya *et al.*, 2019; Arunachalam *et al.*, 2018).

In terms of identifying risks, IoT is a crucial development because it enables data gathering and processing in real-time and therefore enables a higher level of transparency (Aryal *et al.*, 2018). The standardized process structure of SCRM in our use cases revealed a high success rate for identifying micro risks by comparing real-time data with pre-defined values. However, identifying a wider range of risks could reveal hidden correlations and support decision-making. Therefore, additional data sources, such as newspaper articles, weather data or stock prices, should be integrated. Furthermore, this would also conclusions to be drawn on risk prioritization.

As illustrated in our analysis, IoT implementation could improve risk assessment. In particular, the adoption of quantitative methods offers the possibility for an in-depth assessment. However, quantitative methods are underrepresented both in research and in practice and require further development. Furthermore, IoT enables the advancements of disruptive technologies such as artificial intelligence because of its comprehensive data collection and easy integration of additional software (Whitmore *et al.*, 2015).

As our investigated cases primarily focus on the mitigation of risks, there are further potential use cases we want to highlight, which would strengthen the usefulness of IoT systems. For example, in the case of risk acceptance, better quantification of the probability and impact of events facilitates a profound basis for decision making because a better comparison of costs of alternatives can be disclosed. Therefore, even if there was no explicit statement in our interviews, this use case shows many similarities to the risk mitigation and could offers a value addition. Further, the discussed possibility of a retrospective data analysis could improve future risk avoidance. In risk transfer and risk sharing, which seem to be appropriate strategies for risks with a low probability and high influence (Fan and Stevenson, 2018a), IoT offers support through the collection of contract-relevant data. The possibility of a step-by-step system expansion is a core advantage, in addition to the minimization of machine downtime and the possibility of creating meaningful SCRM indicators.

### 5.2 Effects on the internal and external pathway

The successful introduction and use of information processing systems are influenced by several factors. In addition to technological issues, cultural, personal and strategic aspects in particular play an important role in the decision to use advanced technologies (McDermott and Stock, 1999). For this reason, it is essential to analyze internal and external success factors before the implementation and to initiate organizational changes at an early stage (Fan *et al.*, 2017). This internal factor includes, for example, the individual rejection by employees because of their fear of innovations, changes in working habits or the loss of jobs (Birkel *et al.*, 2019). These fears seem unreasonable because our cases highlighted the support for employees through IoT and the reduction of monotonous tasks. Furthermore, the literature emphasizes a culture characterized by a learning orientation as an important antecedent for internal system implementation, comprising the commitment to learning, a shared vision and an open-minded attitude (Braunscheidel and Suresh, 2009). Fan *et al.* (2017) specified these antecedents for adopting information processing systems for SCRM into *SCRM culture diffusion*, *SCRM team support* and *SCRM strategy alignment* and proved their relevance for the implementation. The importance of those cultural aspects is reflected in our sample, as information was, for example, retained because of data sovereignty of different departments. However, no uniform pattern for this behavior could be identified regarding, e.g. the size of the company, the structure of the SCRM or product specificities. However, the culture as a whole and individual employees should be considered. In particular, front-line employees, because they are able to recognize forward suspicious events at an early stage, they can evolve into severe risks (Christopher and Peck, 2004; Khan and Zsidisin, 2012).

However, IoT implementation should not be considered as a mere platform for internal information sharing and processing but as a comprehensive intra- and inter-company linkage. In this context, the external attitude of a company has to be considered (Fan *et al.*, 2017).

IoT thus enables an improvement of the capabilities of suppliers and the supply chain performance through enhanced coordination, which is considered a success factor in the literature (Rajesh *et al.*, 2015; Kilubi and Rogers, 2018) as well as a company-independent strategic risk perspective. This is supported by our finding of improved risk mitigation through IoT in single sourcing relationships and the possibility for continuous supplier audits and evaluation, which enables superior supplier selection. The successful external integration is further improved by networking and partnership capabilities and is generally more developed in externally oriented companies (Kilubi and Rogers, 2018; McDermott and Stock, 1999). Moreover, the implementation requires shared approaches and win-win coordination mechanisms across the entire supply chain, which highlights the focal firm as the coordinating and culture-establishing entity with the highest bargaining power (Fan *et al.*, 2017).

### 5.3 Effects on the supply chain risk management outcomes and barriers to overcome

The improvement of SCRM outcomes and thus organizational performance through technological and innovative capabilities are supported by the literature (Kilubi and Rogers, 2018). As our case study revealed, this is attributable to improved information availability and process management, enabling the fit between increased information requirements and processing capabilities. However, there are certain challenges mentioned by the interviewees, which have to be considered for a successful implementation of the IoT system. In addition to those already mentioned, they focus on technical and financial aspects such as possible infrastructure restraints, lack of comprehensive availability of devices, high error rates of automatically generated risk warnings and the expenses for developing algorithms, IoT devices and the infrastructure. Despite the constant technical improvement and reduction of costs, these aspects are still critical for practitioners, which is in line with the results in the literature (Birkel and Hartmann, 2019).

## 6. Conclusion, implications and further research

Complex business environments, characterized by enormous pressure, shortening product cycles and high volatility, raise the importance of SCRM supported by technological advancements such as IoT. Therefore, our study closes the existing research gap by conducting a multiple case study to gain real-world insights, guided by a theory-grounded research framework to investigate the influence of IoT on SCRM. Based on our case study observations, we offer insights into the practical structure of IoT and derive several propositions regarding the influence of IoT on data availability and process management, the impact on individual process steps, the internal and external pathway and the SCRM outcome. Therefore, our study is extending existing research while offering valuable insights for practitioners.

It reveals the potential of IoT to modify and improve risk management within the supply chain on various layers. Initially, IoT provides quick access to large-scale real-time information from an increasing number of sources, thus ensuring higher risk transparency. In addition, the possibility of merging systems allows for further automation, which increases the velocity of processes and helps to analyze and evaluate the high quantity of data. Furthermore, IoT not only improves processes but affects risk knowledge, risk strategies, job profiles and organizational culture, allowing for an enhanced SCRM performance and competitive advantage. In addition to the internal perspective, the application refines sourcing strategies and supplier selection, which represent a significant potential source of risks for the supply chain itself. The implementation of IoT facilitates a fast, reliable and cost-efficient evaluation of suppliers and related processes while simultaneously offering the possibility for continuous audits and as a result the reduction of uncertainty. However, there are several barriers, such as complex data management, difficult quantification of profitability or resistance of employees, which need to be solved. These issues result in a multitude of future research fields and are an excellent opportunity for the contribution of knowledge.

Despite the valuable contribution of this research to the field of IoT in SCRM, our empirical research design fosters certain limitations, which need to be considered. Furthermore, these limitations offer a great opportunity for further research and shall motivate other researchers to contribute to this field of study.

Even if the case study approach is especially suited for exploratory research (Yin, 2014), the results are strongly dependent on the observed sample and the novelty of the field of research, which thus impairs generalization. Because of this, further industries should be examined. To validate the statements within a company, additional interviews should be conducted. As our research focuses on different companies, another exciting research field would be investigating a single section within the supply chain and analyzing direct relationships between supplier and customer because it enables a more in-depth understanding of the effects of IoT. Because collaboration within SCRM gives reason to expect positive outcomes, continuing research in this direction could generate beneficial insights for practitioners and for academics. Furthermore, the execution of detailed intra-sectional investigations through a large-scale empirical setting with cross-sectional data would allow the testing of the validity of this study's research findings on a more profound basis. Moreover, as this study mainly focused on the effects of IoT on the SCRM of a single company, the consideration of companies that collaborate in the field of SCRM could lead to additional results.

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