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# Smart supply chain risk management - a conceptual framework

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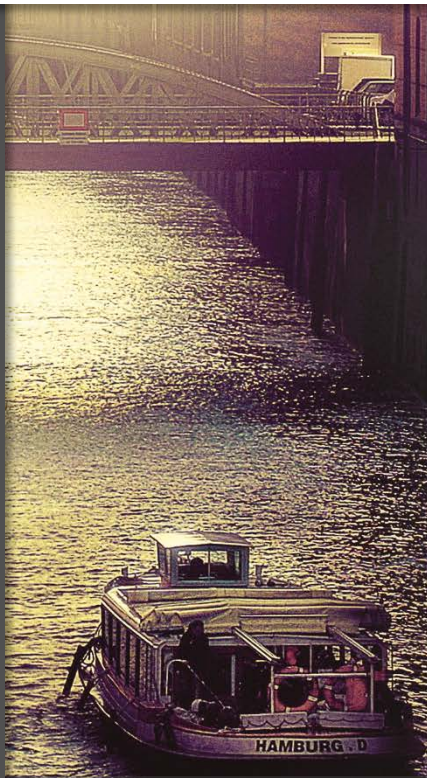
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# Smart Supply Chain Risk Management – A Conceptual Framework

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# Smart Supply Chain Risk Management - A Conceptual Framework

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*Screening existing literature on Supply Chain Risk Management (SCRM) shows that only sporadic attention is paid on real data driven SCRM. Most tools and approaches lead to an expert knowledge based SCRM. Due to the arising topic of digitalization in supply chains, leading to Industry 4.0 (I4.0), there is huge potential in building a data driven, smart SCRM. To speed up research in this direction it is worthwhile to define a new research framework giving direction. To create a consistent framework and define smart SCRM in more detail a literature review will take place to select appropriate dimensions like SCRM phases, readiness stages of Digitalization/ I4.0 and SC perspectives describing the degree of SC collaboration. Afterwards the SCRM and I4.0 dimensions will be put into focus describing what impact I4.0 will have on SCRM leading to future requirements. The new framework serves as a basis for future SSCRM research. It helps to categorize research projects through multiple dimensions and to identify potential research gaps. The developed SSCRM requirements framework is a practical tool guiding the requirement specification when designing a company specific SSCRM system.*

**Keywords:** Supply Chain Risk Management; Industry 4.0; Digitalization

# 1 Introduction

There are many example cases in the literature, like Ericsson (Chopra and Sodhi, 2004; Norrman and Jansson, 2004), Toyota (Pettit, Crocton and Fiksel, 2013) and Land Rover (Tang and Tomlin, 2008), which show that a supply chain disruption and a resulting glitch can have serious cascading effects on all supply chain members and their performance.

To lower the impact of such glitches firms usually establish a supply chain risk management (SCRM) which became a critical supply chain management discipline in the past due to the increasing number of events causing supply chain disruptions (Hillman and Keltz, 2007). In the past usually historical company and external data are used in the traditional SCRM concept (Güller, et al., 2015). The limitation of these practices is that information is not available timely enough and they don't provide a real-time view of the entire supply chain operations (Güller, et al., 2015). Faisal, Banwet and Shankar (2006) have empirically shown the benefit of information sharing of supply chain members to understand the different risks which could have an impact on the supply chain. While supply chain risk information has been identified as crucial, the importance of a firm's information processing capability to its SCRM effort has received little attention in the literature (Fan, et al., 2016). A system which processes SC risk (SCR) information would help firms to respond in a timely manner (Fan, et al., 2017) and enables recognition, analysis and assessment of negative trends to manage risks inside and outside of the SC (Zweig, et al., 2015).

Due to the arising topic of digitalization in supply chains (Pfohl, Yahsi and Kurnaz, 2015; Kersten, et al., 2016) there is huge potential in building a data driven, smart SCRM (Schröder, Indorf and Kersten, 2014). Available real-time information and data-processing tools bring new opportunities for companies to react more quickly to changing conditions within the supply chain (Güller, et al., 2015). The new principles and components of Industry 4.0 (I4.0) (e.g. Hermann, Pentek and Otto, 2016; Siepmann, 2016a; 2016b) lead also to a SCRM based on different principles compared to classical SCRM (Schröder, Indorf and Kersten, 2014; Schlüter, Diedrich and Güller, 2017). Therefore and to speed up research it is worthwhile to define Smart Supply Chain Risk Management (SSCRM) as a sub-research field within the field of SCRM and to come up with a new research framework giving direction.

The purpose of this paper is to create a consistent framework based on existing literature, serving as a basis for future SSCRM research. It helps to categorize

research projects to identify potential research gaps. Afterwards a guiding design instrument for individual SSCRM requirement definitions will be derived. This leads to a practical tool supporting the design process for a company specific SSCRM system.

After a research overview in section 2 the research questions will be defined. In section 3 the framework will be developed and SSCRM will be defined in more detail in section 4. The paper closes in section 5 with a conclusion, an outlook for further research and managerial implications.

# 2 Research Overview

For an appropriate definition of a SSCRM research framework it is necessary to define SCRM and give insights about digitalization and related concepts. The section ends with an overview about related research and the research questions which will be answered throughout the rest of the paper.

## 2.1 Supply Chain Risk Management

SCRM can be seen as an emerging critical and cross-functional discipline between Supply Chain Management (SCM), corporate strategic management and Enterprise Risk Management (ERM) (Hillman and Keltz, 2007; Zsidisin and Ritchie, 2009). In their literature review, Ho, et al. (2015) stated that the proposed definitions of SCRM in the literature usually focus on specific elements of SCRM and do not span the SCRM processes completely or differ in their SCRM methods and types of events. Given this, the authors also follow Ho, et al. (2015) in their definition of SCRM as: “an inter-organizational collaborative endeavor utilizing quantitative and qualitative risk management methodologies to identify, evaluate, mitigate and monitor unexpected macro and micro level events or conditions, which might adversely impact any part of a supply chain”.

## 2.2 Digitalization and related concepts

A digitalized SC makes potential risks visible, allows companies to monitor material flows in real time and to develop future plans (Goh, et al., 2013). The integra-

tion of Cyber-Physical-Systems (CPS) in existing or new supply chain processes leads to a convergence of the physical world and the virtual world (Wan, Cai and Zhou, 2015) and are the foundation of an I4.0 (Bischoff, et al., 2015). CPS are physical objects, equipped with embedded systems, sensors and actuators adding intelligence and the ability for self-control, cross-linking with other CPS and for interaction with their environment (Bischoff, et al., 2015). Beside the term Digitalization there are other definitions in the literature with a similar meaning, like Industrial Internet, Internet of Things, Integrated Industry, Smart Industry, Smart Manufacturing and I4.0 (Hermann, Pentek and Otto, 2016). Especially the term Industry 4.0 or Industrie 4.0 is widely used in German speaking literature and slowly makes its way into Anglo-Saxon literature (e.g. Wan, Cai and Zhou, 2015 or Qin, Liu and Grosvenor, 2016). The main characteristic of the I4.0 is autonomization based on cross-linked systems which communicate with each other via Internet (Roth, 2016). For this paper the term Digitalization is defined as a necessary action on the road to I4.0 and will be used synonymously at some points. More information about I4.0, Digitalization and its components can be found in the literature (Bauernhansl, ten Hompel and Vogel-Heuser, 2014; Bischoff, et al., 2015; ten Hompel and Henke, 2017).

## 2.3 Smart Supply Chain Risk Management

The integration of CPS into supply chains leads to a smart supply chain management, which combines multiple independent data analytics models, historical data repositories, and real-time data streams (Wang and Ranjan, 2015). Through this embedded intelligence, supply chain management moves from supporting decisions to delegating them and, ultimately, to predicting which decisions need to be made (Butner, 2010). The main drivers for the digitalization of supply chain processes are typically an increase in flexibility and reaction rate of industrial/logistic systems (ten Hompel and Henke, 2017). Another perspective is to improve the supply chain robustness by using this available data from digitalized supply chain processes and CPS in SCRM, leading to a smart SCRM. Making the supply chain smarter from a risk management perspective can be described as "SCRM digitalization", thus as: "the integration of technology (sensors, actors, connectivity, analytics) along supply chain processes to improve supply chain risk identification, analysis, assessment, mitigation and monitoring through processing real time supply chain risk information – which comprises supply chain risk information sharing and analysis" (Schlüter, Diedrich and Güller, 2017).

## 2.4 Existing work

In the literature various works for both SCRM and Digitalization can be found which try to guide researchers as well as practitioners in their effort to find and define new research gaps and projects.

In SCRM most of this work is done over the past years via structured literature reviews (SLRs), which are usually based on statistical analysis of the existing literature at the time of release. They are either focusing more on specific SCRM sub-topics (e.g. Tang and Musa, 2011; Fahimnia, et al., 2015; Heckmann, Comes and Nickel, 2015; Kilubi and Haasis, 2016) to show there are specific research gaps or they are more generalized to show multiple research gaps in different sub-topics of SCRM (e.g. Jüttner, Peck and Christopher, 2003; Ritchie, 2007; Singhal, Agarwal and Mittal, 2011; Ho, et al., 2015). Also using the same steps, Schlüter, Diedrich and Güller (2017) performed a literature review to identify literature mentioning how digitalization and the usage of data driven tools will somehow affect SCRM in the near future. While doing so these publications are not focusing on creating a SSCRM, their main purpose is to bring new/better tools into the classic SCRM procedure. A similar publication comes from Schröder, Indorf and Kersten (2014) who postulate briefly how I4.0 will change the steps of SCRM and they propose new risks arising in the I4.0. The above mentioned literature usually focuses on different variations of a SCRM framework, describing the process of SCRM while none attention is paid defining a research framework to structure work in the field of SCRM. To the authors knowledge only the three-dimensional framework by Lindroth and Norrman (2001) can be used to structure work within the field of SCRM. The framework has been further developed and extended by Norrman and Lindroth (2004).

Within the field of Digitalization some framework approaches to cluster current and future research are available. Those are usually focusing on I4.0 in general. Pfohl, Yahsi and Kurnaz (2015) designed a matrix to categorize research within four research-fields, based on the two dimensions “Confirmatory Quantitative vs. Exploratory Qualitative” and “Analysis on management-level vs. Analysis on technology- and process-level”. To give direction for practitioners and researchers the “Dortmund Management-Model for Industry 4.0” by Henke, establishes and formalizes “work-clusters” for transforming value creating activities into the I4.0 (ten Hompel and Henke, 2017).

A recent publication of Lu (2017) gives insights about the development of publication numbers of I4.0 literature and the author has clustered 88 selected publi-

cations in categories like “Concepts and perspectives of Industry 4.0”, “Key technologies of Industry 4.0” or “Applications of Industry 4.0”.

Until now there is no known research framework available in the literature connecting SCRM and Digitalization into a SSCRM research framework, which helps to classify above mentioned research and to identify new research directions and helps to develop a guiding tool for developing company specific SSCRM requirements.

This leads to the following research questions:

RQ1: How does a research framework based on those dimensions look like?.

RQ2: What are appropriate fist definitions of SSCRM maturity steps and role definitions?

## 3 Developing a research framework

The advanced framework of Norrman and Lindroth (2004) serves as basis for the SSCRM.

In one dimension Norrman and Lindroth (2004) introduced five units of analysis in SCRM: single logistical activity within a company (single logistics); logistical activities of the whole company (company logistics); logistical activities between two companies (dyads logistics); logistical activities between companies linked to a chain (supply chain logistics) and logistical activities between companies linked to a network (supply chain network). These different scopes of SCM should be included to reflect the different levels of collaboration presented in the literature.

For the second dimension Norrman and Lindroth (2004) present four SCRM stages but they give no information on why these stages have been selected. Screening existing literature (see section 2) shows that there is a diverse understanding. For a comprehensive framework it is necessary to screen available literature about SCRM steps and build a SCRM procedure based on the findings. A research overview about paper explicitly describing models and frameworks of SCRM comes from Ponis and Ntalla (2016). de Oliveira, et al. (2017) performed a similar approach by screening 27 publications for SCRM steps and comparing them with the ISO 31000-SCRM procedure (see e.g. Curkovic, Scannel and Wagner, 2013). Based on their exhaustive literature review the following SCRM stages will be

Table 1: Industry 4.0 Maturity Stages (Schuh, et al., 2017)

| Maturity stage | Description |
|---|---|
| Computerisation | Support through IT-Systems and worker will be disburdened from repetitive work |
| Connectivity | Systems are structured and connected |
| Visibility | Digital Shadow available and management decisions are data-based |
| Transparency | Companies understand why things happen |
| Predictive capacity | Companies know what might happened and decisions are based on future scenarios |
| Adaptability | Systems react and adapt autonomously |

implemented in the SSCRM framework instead of the original stages of Norrman and Lindroth (2004): risk identification (identification of risks and sources); risk analysis (measurement of risk consequences and identification of risk factors); risk assessment (evaluation of risks); risk treatment (proposal of strategies and mitigation of risks) and risk monitoring (measurement of results, control of risks and ongoing improvement process).

The last dimension of the original framework describes the type of risk: operational, tactical and strategical (Norrman and Lindroth, 2004).

Because a SSCRM connects principles of I4.0 and SCRM the development goes along the same I4.0 maturity stages as mentioned in the literature. Recently the German acatech – National Academy of Science and Engineering published a study to provide companies with I4.0 maturity stages to help them identifying their current maturity stage and also to achieve a higher stage in order to maximize the economic benefits of I4.0 and digitalization (Schuh, et al., 2017). The maturity stages are described in the table below (see table 1).

When speaking about I4.0, the focus is usually on the technological aspects and the important role of CPS, but often neglected is the fact that CPS-based production systems are socio-technical systems (Hirsch-Kreinsen, 2014), consisting of a technical and social subsystem which are interlinked (Bostrom and Heinen, 1977). The social sub system focuses on the role of people using the technology while the technical sub system focuses on the available technology and its role (Bostrom and Heinen, 1977). Because future publications are not necessarily

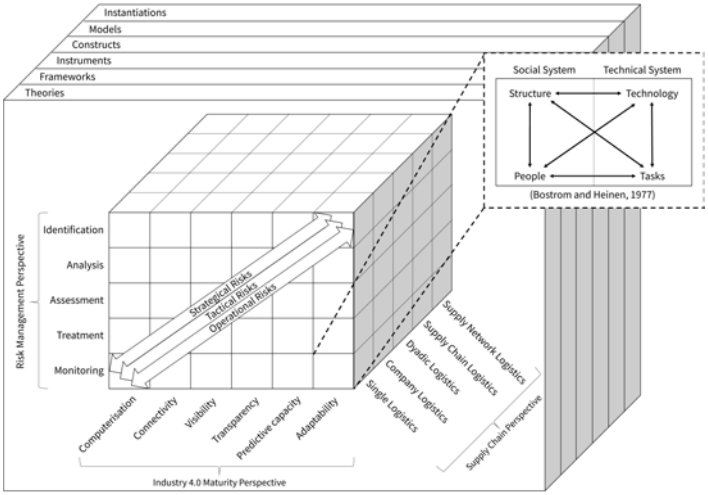



Figure 1: SSCRM Research Framework

focusing on the technological aspects of SSCRM but more on the social aspects and the dynamics between people and technology, the framework should also reflect this.

To speed up research in SSCRM an additional research-outcome dimension is required. The field of Design Science Research (DSR) has strongly formalized possible research outcome in the form of artifacts. DSR has the goal to develop practical solutions that can be used by professionals in their field (Lessard and Yu, 2012). A comprehensive list of how artifacts can look like comes from Hevner, et al. (2004), who mention theories, frameworks, instruments, constructs, models, methods and instantiations.

Combining the above mentioned dimensions delivers the following SSCRM framework, which answers the first research question (see figure 1).

The proposed framework now allows the classification of existing and current research regarding the field of SSCRM. A detailed explanation of the combined

perspectives “Risk Management” and “Industry 4.0 Maturity” follows in the next chapter.

# 4 SSCRM Requirements Framework

To support practitioners in designing SSCRM systems requirements it is helpful to define how the aforementioned I4.0 maturity stages become manifest within SCRM. While the general descriptions of the I4.0 maturity stages (see section 3 and Schuh, et al., 2017) and SCRM (see section 3 and de Oliveira, et al., 2017) are given, the authors defined how the traditional SCRM phases could look like in SSCRM. The goal is to give practitioners a guiding instrument for deriving individual requirements for SSCRM systems throughout the SCRM process, for the technology as well as for the people using the technology.

Due to some similarities between SCRM steps and I4.0 maturity stages (e.g. Risk Analysis and Transparency) it is necessary to specify the objectives within the SCRM phases in an I4.0 context. Due to the digitalization of SC processes, future SC can be understood as data points in a Digital Shadow (Leveling, et al., 2014), leading to the following general SCRM objectives (just for orientation - degree of automatization depends on SSCRM maturity level) (see table 2):

Based on this specification and in combination with the I4.0 maturity stage definitions a framework could be derived, giving overview about potential SSCRM development stages (see table 3 – table 7). For the framework development previous work by Schlüter, Diedrich and Güller (2017) has been used to get an idea how the traditional SCRM phases will change through digitalization. These ideas have been further refined in brainstorming sessions and discussions with other researchers for this working paper. In the future additional research will take place to verify the authors’ ideas.

This first attempt of describing the roles of technology and people within a SSCRM answers the second research question. As it can be seen in the first and second maturity stage there are only marginal difference between the SCRM phases. The reason is that accordingly to (Schuh, et al., 2017) in these stages there is not yet an I4.0 environment and thus there is no infrastructure for a SSCRM available. The SC IT systems serve more as general data sources for risk managers who use the data supportive to traditional SCRM methods. After stage three the technology gets smart and more flexible and can be fitted to SCRM tasks.

Table 2: Overview SCRM objectives in I4.0 context

| SCRM phase | Objective |
|---|---|
| Risk identification | Identification of new risk relevant data points and identification of relations between these points |
| Risk analysis | Identification of directions within the relations to create cause-and-effect relationships |
| Risk assessment | Realistic calculation of risks, based on the relationships between data points and objective quantitative data |
| Risk treatment | Identification of activities through data points and proposing of suitable activities based on effect analysis |
| Risk monitoring | Monitoring of known risks and risk relevant data points as well as chosen activities to ensure risk reduction |

Table 3: SSCRM-Framework – Identification

| I4.0 Readiness Stage | Technical System (Role) | Social System (Role) |
|---|---|---|
| Computerisation | Isolated usage of IT systems in SC processes allows the collection of structured and unstructured process data; Risk relevant information can be stored locally | Manager use the IT system records to identify potential risks in addition to workshops and expert interviews |
| Connectivity | Connection of IT systems allows the uni- or bidirectional exchange of process data; Risk relevant information can be stored in a process wide data base | Manager can use a broader range of SC process data to identify potential risks in addition to workshops and expert interviews |
| Visibility | All SC processes are represented and characterized through data points within a Digital Shadow via real-time data | The user has to recognize critical relations between the data points and define them as risks by himself |
| Transparency | Analytic systems recognize relations between data points (undirected relations) and they search for similar relations | Found relations have to be checked for criticality by the user |
| Predictive capacity | Simulation of scenarios within the Digital Shadow shows future relations between data points and how identified relations will change | Changes of relations and future relations have to be checked for criticality by the user |
| Adaptability | System recognizes potential critical relations between data points, aggregates them to risks and reports them to the user | User monitors the reports and uses the reported potential risky relations and aggregated risks as basis for further assessment and treatment |

Table 4: SSCRM-Framework – Analysis

| I4.0 Readiness Stage | Technical System (Role) | Social System (Role) |
|---|---|---|
| Computerisation | Isolated usage of IT systems in SC processes allows the collection of structured and unstructured process data; Risk relevant information can be stored locally | Manager use different IT system records, in addition to workshops and expert interviews to identify risk causes and patterns |
| Connectivity | Connection of IT systems allows the uni- or bidirectional exchange of process data; Risk relevant information can be stored in a process wide data base | Manager can use a broader range of SC process data, in addition to workshops and expert interviews to identify risk causes and patterns |
| Visibility | Every data point within each risk offers a range of qualitative, structured and semi-structured data | The user has to interpret the data of each data point to recognize cause-and-effect relations (directed relations) |
| Transparency | The system recognizes the cause-and-effect relations based on the real-time information from each data point within and without the identified risk cluster; Data points get ranked based on their influence on other points | The user has to check the data point ranking and chooses the points which should stay in focus for future risk treatment |
| Predictive capacity | Forecasting of changes of direction of the cause-and-effect relations | The user has to check the improved data point ranking and chooses the points which should stay in focus for future risk treatment |
| Adaptability | Based on previous capabilities the system gives suggestions on which data points should stay in focus for risk treatment | User checks the results for plausibility and uses the results for further assessment and treatment |

Table 5: SSCRM-Framework – Assessment

| I4.0 Readiness Stage | Technical System (Role) | Social System (Role) |
|---|---|---|
| Computerisation | Isolated usage of IT systems in SC processes allows the collection of structured and unstructured process data; Risk relevant information can be stored locally | In addition to expert estimations available process data can be used to calculate more reliable values for probability and impact |
| Connectivity | Connection of IT systems allows the uni- or bidirectional exchange of process data; Risk relevant information can be stored in a process wide data base | In addition to expert estimations the available broader range of process data can be used to calculate more reliable values for probability and impact |
| Visibility | Every data point within each risk offers a range of quantitative data and KPIs | Assessment of risks based on the KPIs and comparison with reference values |
| Transparency | Connecting of KPIs and thus improved calculation of impact; Calculation of probability based on a large number of historical and real-time data; Development of new risk measures where necessary | Manual comparison of actual risk values with reference values |
| Predictive capacity | Prediction-based risk calculation gives an overview about the actual and potential risk development | Manual comparison of actual and prediction-based risk values with reference values |
| Adaptability | Comparison of actual and potential risk development with reference values and automatic report in case of significant deviation | User checks the calculated values and reacts when the system gives a report/warning |

Table 6: SSCRM-Framework – Treatment

| I4.0 Readiness Stage | Technical System (Role) | Social System (Role) |
|---|---|---|
| Computerisation | Isolated usage of IT systems in SC processes allows the collection of structured and unstructured process data; Risk relevant information can be stored locally | Treatment actions are developed in workshops and improved cost-value ratio calculation based on process data. |
| Connectivity | Connection of IT systems allows the uni- or bidirectional exchange of process data; Risk relevant information can be stored in a process wide data base | Treatment actions are developed in workshops and improved cost-value ratio calculation based on broader range of available process data. |
| Visibility | Treatment activities are characterized through data points within the Digital Shadow | Based on the characterized risks the user has to identify suitable mitigation actions through the data points as well as to select and initiate them |
| Transparency | The system recognizes relations between risk data points and treatment activity data points and clusters them to potential actions as well as reports them to the user | Found actions and their effects have to be estimated, selected and initiated by the user |
| Predictive capacity | Potential actions will be simulated and the results serve as decision support. Additionally potential negative impacts on other risk data points can be recognized in advance | User chooses the actions with the best possible outcome or with the least side effects |
| Adaptability | After the evaluation the system decides autonomously about the initiation of mitigation actions | User checks the chosen actions and intervenes/-corrects if necessary |

Table 7: SSCRM-Framework – Monitoring

| I4.0 Readiness Stage | Technical System (Role) | Social System (Role) |
|---|---|---|
| Computerisation | Isolated usage of IT systems in SC processes allows the collection of structured and unstructured process data; Risk relevant information can be stored locally | At discrete points in time manager come together and discuss about monitored risks and initiated treatment actions, supported by available process data |
| Connectivity | Connection of IT systems allows the uni- or bidirectional exchange of process data; Risk relevant information can be stored in a process wide data base | At discrete points in time manager come together and discuss about monitored risks and initiated treatment actions, supported by a broader range of available process data |
| Visibility | Identified risks and where necessary initiated actions appear as individual entities in the Digital Shadow | User has to recognize plan deviations by himself and identify the reasons |
| Transparency | In case of a plan deviation the system tries to identify the reasons and reports them to the user | Based on the reports the user has to adapt the initiated actions or choose other options reactively |
| Predictive capacity | Due to a projection of the digital shadow into the future potential plan deviations and reasons can be recognized in advance; Corrective actions and their effectiveness can be simulated in advance | Based on the reports the user has to adapt the initiated actions or choose other options proactively |
| Adaptability | Autonomous correction of actions in case of a potential plan deviation | User supervises the system and corrects actions in case when plan deviations cannot be contained through the system |

# 5 Conclusion and Further Research

The paper presents a first approach of establishing SSCRM as sub-research field of SCRM by proposing a specific research framework. The framework has been created by reviewing literature from the field of SCRM and I4.0. Afterwards a framework with SSCRM requirements has been developed as a guiding design instrument.

## 5.1 Limitations and further research

The proposed framework is only one way to define the sub-research field of SSCRM and was created by combining an established SCRM research framework with recent literature about I4.0. When more literature is available, further research can be suggested for testing if these dimensions are sufficient or additional dimensions have to be considered. Also the SSCRM phases and based on that the roles of technology and people within the SSCRM maturity stages have been postulated by the authors. Additional research will be undertaken to verify the authors' ideas, leading to generalized roles for individual requirement derivation. It also has to be noted that some framework dimension combinations may not allow some of the artifacts as a research outcome. This issue can be solved through screening future literature focusing on their position in the research field and their outcome.

## 5.2 Managerial Implications

The smart SCRM developed here is a good basis for a proactive SCRM which in the literature is discussed on a conceptual basis for many years (e.g. Henke, 2009) but up to now it has rarely been realised in business practice. In the age of Big Data, digitisation and autonomisation today we have sufficient data as well as the technologies (such as blockchain), which can allow a proactive management of such data along supply chains. The transparency in value-added networks exists end-to-end so that in the future risks can be avoided or reduced at an earlier stage than today. For a practical application of such a SSCRM it is also necessary that there is a structured approach from application-oriented research to core elements of a cycle of SSCRM.

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