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Migration framework for decentralized and proactive risk identification in a Steel Supply Chain via Industry 4.0 technologies

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Abstract

For competitive risk mitigation in future steel supply chain networks a decentralized risk identification corresponding to the 4th Industrial Revolution is required. By integrating Cyber-Physical-Systems (CPS) in supply chain networks, a large number of real-time data in different formats will be available and must be consolidated. A framework is missing that leads to an improved risk identification and mitigation process by linking risks and CPS. In this paper a framework will be presented which correlates identified supply chain risks, suitable Industry 4.0 (I4.0) technologies and relevant finance indicators. The framework enables to identify relevant risks and their potential impact on companies' assets and working capital, and also gives advice how these risks can be registered in advance by using I4.0 technologies.

KEYWORDS

Supply Chain Risk Management, Cyber-Physical-Systems, Industry 4.0, Steel Industry

1. INTRODUCTION

Steel manufacturers are an inseparable part of several complex supply chain (SC) networks and deliver key resources for different manufacturing industries such as automotive, machineries and building companies. Operating this complex SC network is accompanied by several operational risks [1]. To ensure SC security as well as to support the competitiveness of steel companies and their customers it is necessary to identify potential risks in steel SCs in advance. But in reality insufficient IT networks between SC partners lead to unstable and prone transport chains. This leads to storage and transport bottlenecks and therefore to expensive ad-hoc solutions [2] like additionally rented transport capacity. A SC wide proactive risk management based on risk related information transparency is required to increase the security of supply, decrease safety stocks and lower costs for steel manufacturer and their customers [2, 3]. The potential advantages from a proactive supply chain risk management (SCRM) based on information transparency and corresponding to the 4th Industrial Revolution have been recognized by Zweig et al. [4]. In their study the authors state that disruptions in steel SC can have a serious impact on the companies' competitiveness and threaten their existence. A digitalized SC (including Machine-to-Machine-Communication) makes potential risks visible and allows companies to monitor material flows in real time and to develop future plans with the help of predictive analytics. A system is essentially needed which enables recognition, analysis and assessment of negative trends to manage risks inside and outside of the SC [4]. To support the development of a SC wide risk related information transparency and to make a first step towards a digitalized SCRM, this publication presents a procedure framework for supporting the migration of I4.0 technologies. The contribution is broken down into 5 sections. After the introduction in section 1 follows a state of the art analysis of existing approaches in section 2. Derived from this analysis the developed framework is introduced in section 3 and partially applied on an example steel SC in section 4. Section 5 summarizes the findings of this paper and discusses the need for future developments in SCRM.

2. RESEARCH OVERVIEW

A generalized and standardized risk management (RM) process was developed by the International Organization for Standardization [5] and consists of six phases [5, 6]. This generalized RM process is also suitable for the specified SCRM process [7]. In addition to the standardized process [5, 7] the "risk" is separated in the components "source", "event" and "effect" which can be integrated in a cause-and-effect relationship (network) [8]. In general SCRM methods can be distinguished between qualitative and quantitative methods [9]. The advantages of qualitative methods like interviews and estimations, lie in less need of personal resources and available data [9, 10]. However these methods are only suitable for risks with a low need for assessment accuracy and a low probability of occurrence [9, 10]. Once it comes to risks with a high occurrence rate, it is necessary to use quantitative methods [9, 10]. In practice quantitative methods like statistics, optimization models and simulations are not frequently applied, because of lacking available data [9–11]. Though there is an empirical evidence for the need of more quantitative and analytical methods as well as special IT support for RM in companies [11]. One step to overcome this lack is the implementation of I4.0 technologies into supply chain processes. Generating a continuous data basis along SC partners creates transparency and supports a more quantitative and real time SCRM. More detailed information about I4.0, its definition and paradigms can be found in further literature [12–15].

3. FRAMEWORK DEVELOPMENT

In this section a framework for digitalizing the risk identification process will be developed. The framework is based on earlier developments by Kirazli and Moetz [16] and Yüzgülec [7]. Kirazli and Moetz [16] provide a methodological four-phase concept for the introduction of I4.0 from a RM perspective. But there is a lack of specific I4.0 technologies and the article has a focus on potential risks through the implementation of I4.0 technologies. Therefore they do not cover the digitalization of general SC risks for a proactive recognition. With the help of the detailed SCRM process of Yüzgülec [7] the four-phase-concept of Kirazli and Moetz [16] has been adapted to a five-phase-concept which leads the user through the required steps to derive strategies for migrating I4.0 technologies for proactive risk identification. The five-phase-concept is presented in Table 8 with a succeeding description of applicable methods in each phase.

Table 8: Five-Phase-Concept for Industry 4.0 Risk Identification

Phase	Objectives	Methods
1. **Process specification**	• Structured description and visualization of the SC process and its sub processes • Definition of process condition measures (PCM) (performance indicators for Phase 5)	• Process inspection • Process model • Expert interviews • Workshops
2. **Risk identification**	• Identification of risks for each process	• Collection methods • Search methods (analytical/creative)
3. **Risk analysis**	• Cause-effect analysis of identified risks (sources, events and effects) • Determining of direct impact of risks on PCM	• Process model and inspection • Determination and visualization of risk causalities
4. **Risk digitalization**	• Examination of future developments and applications • Derivation of migration-strategies for I4.0 technologies (not part of this paper)	• Technology management ➢ Technology scouting and forecasting ➢ Technology strategy and roadmap
5. **Cost-benefit-Analysis** (not part of this paper)	• Assessment of risk impact on SC costs/performance by using KPIs • Assessment of potentials of using I4.0 tech. for SCRM	• Comparison ➢ Impact of risks on KPIs ➢ Impact of tech. on risks (occurrence/loss) ➢ Expenditures for tech. implementation

Within the five phases, different methods have to be applied. For the process specification phase the process chain instrument (PCI) by Kuhn [17] can be used for visualizing the process chain as well as for defining process condition measures (PCM) as variables for performance indicators. Kuhn [17] defined five measures for determining the condition of a single process: inventory, lead time, adherence to delivery dates, capacity and process costs. Other visualization methods can be found at Jungmann and Uygun [18]. But how to link this measures systematically to key performance indicators (KPI)? There are several KPI-systems in supply chain management which provide indicators for process measuring and corporate objective evaluation at the same time (see [19–21]). Next to SCOR the Supply Chain Balanced Scorecard (SCBSC), based on the Balanced Scorecard from Kaplan and Norton [22] offers a set of different KPI's and measurement categories. The SCBSC-framework allows an evaluation with the help of five different evaluation-perspectives: "finance", "customer", "internal process", "supplier" and "development". In this contribution the finance-perspective is integrated into the five-phase-framework. Typical corporate finance objectives are success, liquidity, profitability and the companies value add while reducing the process/supply chain costs and working capital costs [23]. Potential finance indicators are revenue, earnings before interest and taxes (EBIT), return on capital employed (ROCE), cash-to-cash-cycle, return on invest (ROI), economic value added (EVA) and working capital and supply chain costs [23]. Romeike and Hager [24] present a collection of risk identification methods divided into collection methods for identifying existing and partially known risks and search methods (analytical and creative) for identifying future risk potentials. Typical approaches which are also used by Häntsch and Huchzermeier [25] to identify risks in car manufacturing networks are: risk checklists, expert interviews and workshops. During the risk analysis phase a cause-effect-analysis for all identified risk sources, events and effects has to be carried out. Afterwards the direct impact of the initial risk sources on their corresponding process has to be determined. An approach for risk synthesizing with several methods comes from Yüzgülec [7], based on a methodology of Lingnau and Jonen [26], as well as methods for determining the direct impact of risk sources on process condition measures. When the SC risks, their correlation and the impact of their initial sources on the performance indicators are known, a technology scouting must be executed. A comprehensive collection of approaches for technology scouting and forecasting from the field of technology management can be found at Schuh and Klappert [27]. But it is also possible to use existing publications like [14] or [28] as decision support for choosing I4.0 technologies. The fifth and last phase consists of a cost-benefit-analysis which evaluates the implementation and use of I4.0 technologies within SCRM and thus gives recommendation about whether the implementation is worthwhile or not. Methods for technology evaluation are provided by Schuh and Klappert [27]. Regarding these methods and KPI's of the SCBSC an assessment of I4.0 technologies in SCRM such as a business case evaluation can be carried out.

4. CONCEPT APPLICATION

In this section four phases of the model will be applied in a use case of a German steel manufacturer.

1. Process specification

For the process specification phase the PCI by Kuhn [17] can be used for visualizing the process chain and defining PCM for the development of KPIs (see Table 9). In this case an aggregated SC is displayed in Figure 2 with focus on the material flow.

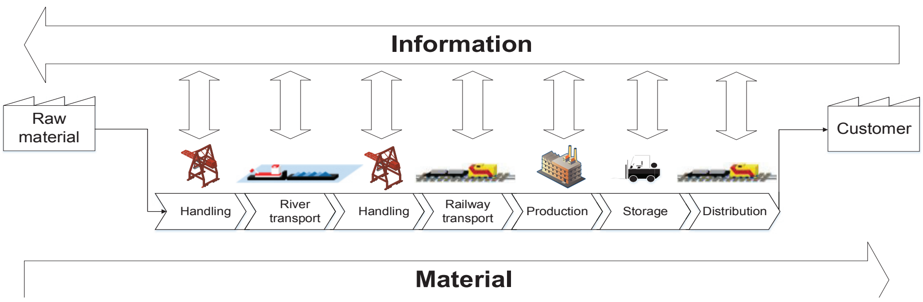

Figure 2: Example steel supply chain

2. Risk identification

Expert interviews at the logistics department of a German steel manufacturer took place, based on interview methods by Yüzgülec, Romeike and Hager as well as Häntsch and Huchzermeier [7, 24, 25]. The interview partners were asked about typical risk events and their sources for handling, river transport, railway transport, warehousing and distribution processes. The most frequently mentioned risk for each process will be used for the risk analysis (see Table 9).

3. Risk analysis

The chosen risks are not directly linked to each other. Therefore it is not necessary to create a comprehensive cause-and-effect relationship network and only the direct impact of defined risk sources on process condition measures (risk effect) have been discussed (see Table 9). However generally all identified risk sources, events and effects throughout the defined processes have to be analyzed and correlated (see Table 9).

4. Risk digitalization

For improving risk identification with the help of I4.0, available technologies have to be matched to the identified risks. In this case an existing study like [14] is used to introduce technology fields as categories, combined with exemplary risk-related technologies from [28] (see Table 9).

Table 9: Integration of Risks, Technologies and KPIs

Technology Fields				Process Condition Measure	KPIs
Machine Interface	**Sensors**	**Software/ System-technology**	**Embedded Systems**		
• Live-tracking of crane controls	• Vibration • Weight • Temperature • Humidity • Movements • Position (GPS)	• Simulation • Pattern recognition • Digital maintenance protocols • Digital BOM	• Smart and miniature systems	• (Handling) Capacity	• SC-costs and working capital costs with impact on EBIT and ROCE
• -	• Temperature • Draft • Position (GPS) • Tide	• Simulation • Pattern recognition • Big-Data storage and analytics • Web Services (Weather/ News) • Digital maps/ schedules	• Smart and miniature systems on boats	• (Trans-port) Capacity	• SC-costs and working capital costs with impact on EBIT and ROCE
• -	• Temperature • Position (GPS) • Humidity • Belt speed	• Simulation • Pattern recognition • Web Services (Weather)	• -	• (Handling) Capacity	• SC-costs and working capital costs with impact on EBIT, and ROCE
• Live-tracking of train controls	• Temperature • Vibration • Position (GPS) • Humidity • Weight	• Simulation • Pattern recognition • Big-Data storage and analytics • Web Services (Weather/ News) • Digital maps/ schedules	• Smart and miniature systems on trains and on bridges	• Lead time	• Costs SC-costs and working capital costs with impact on EBIT and ROCE
• Live-tracking of crane controls	• Temperature • Vibration • Weight • Movements	• Simulation • Pattern recognition	• -	• Stock	• Working capital costs with impact on EBIT and ROCE
• -	• Temperature • Position (GPS) • Humidity • Weight	• Simulation • Pattern recognition • Web Services (Weather)	• Smart and miniature systems on wagons	• Costs	• SC-Costs with impact on EBIT, revenue and ROCE

Process	Risk event	Risk source	Communi-cation
Handling (Sea port)	• Crane is blocked	• Component breakdown	• Real time • Wireless • Stationary
River transport	• Reduced load capacity	• Low tide due to long term high temperature	• Real time • Wireless • Stationary /Mobile
Handling (Plant port)	• Belt conveyor blocked	• Frozen components due to low temperature	• Wired • Stationary
Railway transport	• Railway blocked	• Railway bridge broken due to obsolescence	• Real time • Wireless • Stationary /Mobile
Storage	• Reduced storage capacity	• Coil basins broken due to obsolescence	• Real time • Wired
Dis-tribution	• Coils get damaged (rust)	• Condensate water	• Real time • Wireless • Mobile

Based on these recommendations digitalization strategies can be derived. Afterwards these strategies have to be assessed within a cost-benefit-analysis.

5. CONCLUSION AND OUTLOOK

The objective of this paper was the development of a framework to support the migration of I4.0 technologies into SCs for an improved risk identification. Therefore the authors presented a brief research overview regarding I4.0 and SCRM. Based on that a framework has been developed. The framework consists of five-phases with different methods in each phase. The developed framework has been applied to a use case of a German steel manufacturer to show the applicability. One of the implications for further research is to add a cost based assessment to the suggested method of Yüzgulec [7] as well as a methodology to model the advantages of the I4.0 technologies in the simulation. Another implication is to find other suitable assessment methods, depending on more or less detailed requirements by the user. The developed framework only considers the risk identification phase of the SCRM process. Further development is needed to extend the framework to the risk assessment and control phase. There is also a need for further research regarding the applicability to other use cases and regarding the deviation of digitalization strategies.

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