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BIG DATA-ENHANCED RISK MANAGEMENT

Summary

Today's global and complex supply networks are susceptible to a broad variety of internal and external risks. Thus, comprehensive and innovative approaches to risk management are required. This paper addresses the question of how Big Data can be used for the implementation of an advanced risk management system. A conceptual framework covering three major dimensions of Big Data-driven risk management, i.e. type of risk, risk management phases and available technology, is introduced. Additionally, selected application examples for early detection, assessment, mitigation and prevention of risks in supply networks are provided.

Key words: *Risk Management, Supply Networks, Digitalisation, Big Data*

1. Introduction

Global supply networks are the basis for gaining access to raw materials, suppliers, and markets. Although these global networks provide substantial advantages and potentials for all companies involved in the supply chain, they also contain substantial risks mainly coming from a high degree of vulnerability and exposure of intra- and inter-company production and logistic processes to unforeseen events. [1] Thus, real-time reactions to disturbances, especially of time-critical processes, become increasingly important. Accordingly, John Chambers, the chairman and chief executive officer of Cisco Systems, made the following remark after the earthquake in Japan: "In an increasingly networked world, supply chain risk management is top of mind in global organizations as well as a key differentiator for leading value chain organizations". [2]

As a consequence, innovative approaches to supply management have gained importance in recent years. Generally, supply chain management is a widely accepted concept for the target-oriented management of (global) supply chains and networks. In today's complex and dynamic environment, risks in the supply chain constantly endanger the profitability of the companies involved. Therefore, approaches like risk-adjusted supply chain management including structured risk management and an early-warning system can potentially avoid or mitigate risks, leading to a further improved financial performance and competitive advantages. [3]

Recent developments in the field of digital technology have improved support for approaches like risk-adjusted supply management. The application of innovative technologies, in-memory computing, the Internet of Things (IoT), and Radio Frequency Identification (RFID), can facilitate establishing globally interconnected manufacturing and logistics systems. This leads to greater transparency and agility, and consequently to the ability to manage the constantly increasing dynamics and complexity of global supply networks. [4]

2. Research Purpose and Methodology

This paper addresses the question of how Big Data potentially affects risk management in supply networks. For this purpose, the currently ongoing transformation of supply chains into supply networks is outlined first. This sets a basis for the analysis of major risks lurking in such networks. Furthermore, a risk management cycle is introduced as the methodological basis representing one dimension of the framework for Big Data-enhanced risk management developed subsequently. In contrast to existing approaches, this framework aims at providing a comprehensive view of risk management by integrating two additional dimensions: the type of risk and the technology that can either avoid or minimize risk.

3. Transformation of Supply Chains into Supply Networks

One of major challenges facing global companies are planning, managing and controlling their supply chains. [5] So far, the global division of work processes has shaped modern supply chains, leading to economic benefits – especially for industrialized countries. In this context, the supply chain is considered as a linear chain in which the material, information and finances flow linearly in one direction from suppliers to producers, retailers and end customers. This process is ongoing as companies are still deciding on whether an intensified participation in global supply chains may increase their profitability. Today, discussions and decisions in supply management mainly take place in the context of "make, cooperate or buy". Companies do not act as a self-contained construct anymore, but rather consider collaborative partnerships as a sustainable competitive advantage. [6]

Previously, supply chain professionals managed the "Four V's - Volatility, Volume, Velocity, and Visibility" in order to optimize objectives, such as total cost or service quality. [7] Although still valid, these objectives are currently challenged as digital technologies enable innovative approaches to the setup, organization, management, and hence to the performance of global supply chains. [8] Originally, the main driver for the development of inter-organizational supply networks was the application of internet technologies for information allocation. [9] Recent developments in digitalisation and digital technologies have accelerated the transformation of supply chains into complex and globally interrelated supply networks with numerous interfaces and channels. The horizontal integration of these supply networks has to consider a vast number of requirements of systems, processes and cultures coming from different companies and locations. [10] Since the external environment of such networks has also become more complex and increasingly volatile, the planning and management efforts together with the inherent risks of global supply networks have grown significantly.

4. Risk Management in Global Supply Networks

Today, companies are exposed to a large number of risks resulting from market globalisation, reduced product lifecycles, complex networks of international partners, unpredictable demand, uncertain supply, cost pressure, necessity to be lean and agile, increasing outsourcing and off-shoring, and dependency on suppliers [11]. In the specific context of logistics and supply chain management, risks may arise from the complexity of the market characterized by the shortage of suppliers, replacement products and technologies. [12] More comprehensively, the supply chain risk can be considered as any risk to the flows of information, material and product from the original suppliers to the delivery of the final product to the end customer. [13] According to March and Shapira, the supply chain risk is "a variation in the distribution of possible supply chain outcomes, their likelihood, and their subjective values". [14]

Merging the two definitions stated above and considering the different types of flows generated between the cooperating companies, the supply chain risk is considered in this paper as an adverse effect on the flows between various elements of a supply network. Variability may affect the flow of information, goods/materials and/or financial resources. Therefore, the following risk assessment is based on three risk segments representing these flows within a supply network:

a) The physical movement of materials and products from suppliers to customers is referred to as material flow. Even in a small and structured supply chain, there is a certain risk that the material is not provided on time, in the expected amount and quality at the designated place/company. Due to greater interconnectivity and the influence of the bullwhip-effect in supply networks, this risk increases exponentially. Additional risks to the material flow in supply networks are related to global sourcing. The extensive application of this sourcing strategy leads to significantly longer transport distances and times and consequently to a greater susceptibility of the entire network to unforeseen events, such as political crises, terrorist attacks or natural disasters. Other elements of material flow risk that need to be considered are single sourcing risk, sourcing flexibility risk, supply capacity risk, supply selection and outsourcing risk, production risk, operational disruption, demand volatility, etc. [15]
b) Financial impacts of variations and/or disruptions in the material flow consist of lost turnover, increased cost due to higher inventories, penalties, and lower cash flows. Besides these derivative monetary effects, one major financial flow risk is the exchange rate risk. In global supply networks, exchange rates have a significant influence on companies' after-tax profit, supplier selection, market development, and other operational decisions. [15] Price and cost risks may also arise from the scarcity of raw materials or fluctuations on international commodity markets. [16] Another major element of the financial flow risk is the financial strength of network partners. The financial weakness of a network member may easily affect the entire supply network not only in terms of financial but also of material flows. [15]
c) The high complexity and dynamics of global supply networks require multiple information flows in parallel to the material and financial flows. These information flows are not only needed for the collaborative organization and coordination of the network in day-to-day operations, but also for having the necessary strategies for managing risks and disruptions. Information technology is widely perceived as an important facilitator in the collaborative (risk) management of supply networks. [17] Therefore, the information accuracy risk is a major threat to the information flow as it hinders or prevents the prompt interchange of relevant information among network partners. Considering the current state in business practice, this risk is still present because a variety of information systems and the current information technology operated by supply networks often negatively affect interoperability and information flows. [18] Another element of the information flow risk is the information system security and disruption, which may be caused by the lack of professional IT-management, hackers, or natural disasters. [15]

Due to a high degree of integration and interdependency, every stage or process within a supply network carries an inherent risk potentially affecting the entire collaboration. Hence, a comprehensive risk management framework is required. The objectives of such risk management are to identify possible risk sources within and outside the supply network and to develop appropriate action plans. Therefore, the risk management cycle consisting of three different stages is applied in this study in order to keep the influencing risks on a low level.

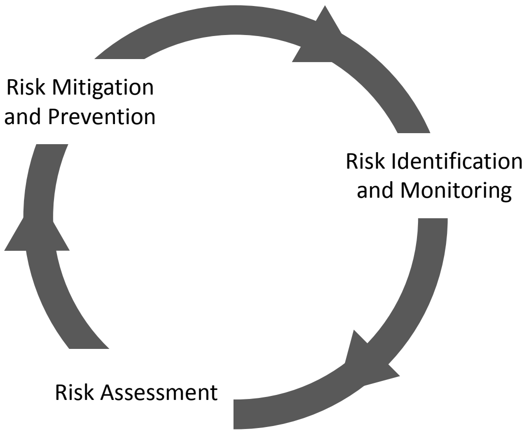

Fig. 1 Risk management cycle

a) Risk Identification and Monitoring: This initial stage of the risk management process identifies risks and their potential causes. Common risks together with extra risks have to be determined. Hence, the main focus of risk identification is to recognize future uncertainties to enable proactive management of risk-related issues. Risk factors, such as suppliers, countries, and transportation systems, are monitored and evaluated by various key performance indicators (KPIs). The level of an in-stock inventory, production throughput, capacity utilization, and delivery lead times are some of the KPIs that can be applied to identify an abnormal situation that may involve a potential risk. If there is a significant deviation from the standard in a KPI, the alarm is triggered, establishing an early-warning-system. [17, 19]
b) Risk Assessment: After identification, an assessment is required in order to prioritize risks and take specific management actions. Probability of occurrence, risk level and risk impact are criteria that are widely used for differentiating risk. Consequently, the use of probability functions and historical data is necessary. Due to a relative lack of data (data are often available for risks such as currency rate and lead time but are usually rare and insufficient for events like earthquakes and terrorism), risk assessment can be rather difficult. Moreover, risk impact is usually expressed in terms of cost, but performance loss, physical loss, psychological loss, social loss, and time delay also have a significant impact on the company and therefore on the supply network. [20]
c) Risk Mitigation and Prevention**:** Based on the data collected and assessed in the previous stages, risk mitigation aims at the elimination of identified risks or the reduction in the degree of their probability of occurrence and/or their impact. For this purpose, risk mitigation strategies are implemented by adopting two conventional approaches. In the reactive approach, no action is taken before the risk has materialised but there is a strategy in place to lower the impact. In this strategy, no plan to reduce the probability of occurrence is considered. In the proactive approach, strategies are implemented to mitigate the risks before they materialise. Proactive mitigation plans are implemented in order to decrease the probability of occurrence rather than to reduce a potential impact of a materialised risk. [20]

Applying Big Data to traditional risk management approaches may result in potential enhancements of the process and consequently in a significant reduction in the level of the overall risk to the entire supply network.

5. The Concept of Big Data

Although there is no universally accepted definition, a common understanding of Big Data has been established in science and practice. This understanding is based on the major characteristics of Big Data – the four V's. [21]

- Volume is the most visible aspect of Big Data. Currently, data volumes in the range of gigabytes and terabytes can be processed. As the range will continue to increase, the data unit of a petabyte will be widely available in the foreseeable future.
- Variety describes the availability of data in many different forms, ranging from machine data to relationship data. This data can be structured, partly structured or completely unstructured and can be generated by internal as well as external data sources.
- Velocity means the real-time acquisition, transformation, processing and analysis of streaming data generated by sensors and embedded systems or data coming from the web. This can be obtained by applying in-memory computing.
- Veracity describes the confidentiality of captured data, which depends, for instance, on the quality of data collection and secure transmission channels.

Thus, Big Data is able to combine different data sources and various types of structured and unstructured data. Additionally, it allows for the analysis of large amounts of data in real time, which has not yet been possible.

6. Big Data-Enhanced Risk Management Framework

In order to assess the potential implications and benefits of Big Data for the risk management in supply networks, a methodological framework needs to be developed. For this purpose, a three-dimensional approach will be applied covering the two major aspects of risk management in supply networks: the type of risks as one dimension and the phases of the risk management cycle as the other. Additionally, a third dimension is to be introduced addressing the major technologies in the area of Big Data (Fig. 2).

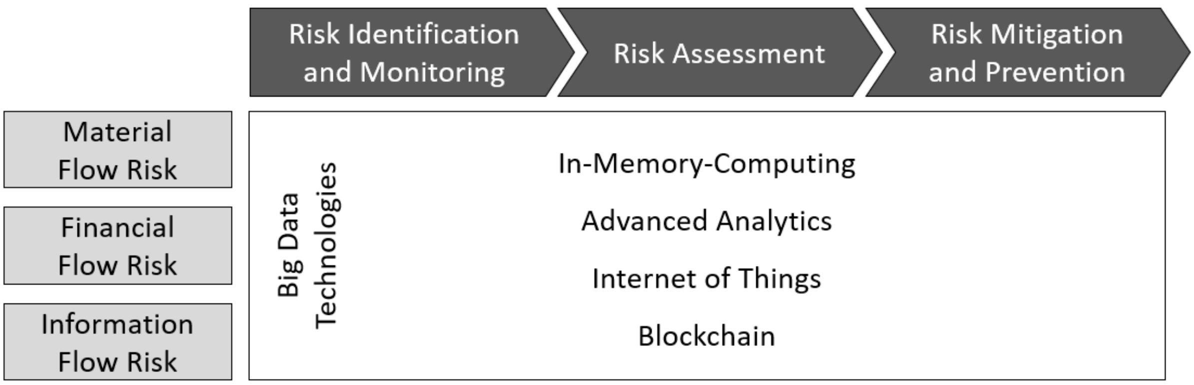

Fig. 2 Big Data-enhanced risk management framework

The main technologies that are discussed extensively in the context of Big Data are in-memory computing, advanced analytics, the Internet of Things, and blockchain.

- In-memory computing is an approach where data is no longer stored on hard disks but constantly provided in the random-access memory of information systems. This allows more rapid access to this data and its real-time processing. [22]
- The concept of advanced analytics is largely based on in-memory platforms aiming at integrating and analysing large amounts of various data coming from different internal and external sources. Thus, advanced analytics allows constant monitoring of relevant data sources leading to an event-triggered analysis and timely reactions to internally and externally induced variations in the material, financial, and information flows. Additionally, advanced analytics can be utilised to predict future developments and risks by a statistical analysis of historical data. [23]
- The Internet of Things (IoT) is a new paradigm which can be defined as a dynamic global network infrastructure consisting of a variety of devices or things such as RFID tags, sensors, mobile phones, and actuators, which are able to interact with each other through addressing schemes and self-configuring capabilities or collaborate with their neighbours to reach common goals. [24, 25] In the context of supply networks, this concept not only increases transparency but also allows for innovative, decentralised planning and coordination approaches for global material flows.
- A promising technology for solving security-related risks is the blockchain technology as it constitutes the foundation of trust-free economic transactions based on its unique technological characteristics. [26] This innovative technology refers to a distributed database for capturing and storing a consistent and immutable event log of transactions between network actors. In a supply network, all actors have access to the history of transactions. As the current blockchain technology not only processes financial transactions but can also ensure compliance of transactions with programmable rules in the form of smart contracts, a high potential for risk prevention in supply networks may be assumed. [27]

The following discussion of the impacts of these technologies on the risk management in supply networks and their benefits follows the phases of the risk management cycle. Based on these phases and considering the different types of risks in supply networks, selected application examples are discussed in detail.

Risk Identification and Monitoring

Identification and monitoring of *material flow risk* can be enhanced by using sensors, RFID tags and embedded systems in order to continuously track materials and products within the supply network. Additionally, data from external service providers like insurance companies need to be integrated because external events, such as political unrests, disasters or strike calls, may significantly disturb or even disrupt the material flow in global supply networks. These sources generate a vast amount of streaming data that needs to be monitored, processed and shared in real time throughout the supply network. This can be achieved by utilising in-memory computing systems that are capable of constant monitoring of data streams based on certain rules or even complex algorithms. In case of an exception, an alert can be issued or certain processes within the supply network can be initiated. [28]

Financial flow risk may be divided into a systematic and an unsystematic risk. The systematic financial flow risk is driven by generic external factors outside the network (e.g. economic fluctuations and crisis). Thus, monitoring this risk requires the consideration of external data coming from different sources like financial markets, banks, and rating agencies. Due to the fluctuating dynamics of systematic financial flow risk, a fast identification of relevant risks is crucial, requiring processing of this data in real time. Unsystematic financial flow risk refers to the partners engaged within the supply networks. Changes in their financial stability and performance need to be detected early by monitoring data coming from credit rating agencies but also additional data, e.g. the data from social media. By implementing statistical algorithms, early warnings on the financial perspective can be generated. [29]

Information flow risk threatens the key capability of a supply network to deliver the relevant information to respective decision makers on time due to delayed or disrupted data transmission. An early detection of missing or distorted data may be achieved by using in-memory-based streaming analytics. Data streams coming from different sources inside and outside the networks are processed and verified in real time based on rules or concepts such as machine-learning. [30]

Risk Assessment

Traditional approaches and IT-systems cannot be used in in the suggested enhanced risk management framework due to the volume, variety and velocity of data that needs to be considered. Rather, innovative Big Data technologies need to be implemented in order to increase effectiveness and efficiency of risk management in supply networks by calculating automatically the probability of occurrence, the impact and the level of risks.

This is achieved by combining data-oriented stochastic approaches and deterministic models. The stochastic prediction is based on data acquired from various internal and external sources by applying statistical and mathematical algorithms in order to assess the risk probability. These results are then processed in a driver-oriented model that calculates the impact of the risk on certain key performance indicators, such as delivery time, credit score, and return on investment, based on defined cause-effect chains. This leads to a comprehensive risk level assessment. [31]

By applying in-memory computing, processing of data streams can be automated and executed in real time. This allows immediate reactions to identified high-level risks. Additionally, a sensitivity and what-if analysis can be carried out leading to a more thorough and in-depth risk assessment.

Risk Mitigation and Prevention

After having identified and assessed potential risks in the supply network, Big Data can help to eliminate or reduce the probability of occurrence and/or the impact of an identified risk.

In-memory computing significantly reduces a *material flow risk* by enabling the fast execution of the Manufacturing Resource Planning (MRP) process. Previously, the necessary calculations and process steps had to be done using batch processing in an enterprise resource planning system or an advanced planning system. With the application of in-memory computing, the MRP run can be triggered without time delays, potential material flow risks coming from e.g. a changing sales forecast; in addition, irregularities or interruptions in the material flow can be better managed. [32] Mobile devices together with advanced analytics allow timely recognition of disturbances or disruptions in the logistics chain and consequently preventive or corrective actions to secure supplies, e.g. by redirecting transport flows. Thus, rapid reactions to deviations or failures in every single stage of the supply chain are possible. [15]

Advanced analytics can also help mitigate or prevent a *financial flow risk* as it uses statistical methods and machine-learning techniques to support decisions on accepting or rejecting a customer or a partner, increasing or decreasing the loan value, interest rate or term. The speed and accuracy of decisions represent a major benefit of innovative approaches to the management of financial flow risk. Additionally, these approaches and techniques can also be used for automated risk mitigation actions like forward exchange transactions.

Mitigation and prevention of *information flow* risk can be achieved by using IoT-based standard services. Other than traditional interfaces, these standard services and protocols allow the flexible integration of different IT-systems within the supply network. By combining the IoT services with in-memory systems, information can be shared in real time among all relevant partners. Real-time monitoring of the data flows within the network allows us to prevent and mitigate information flow risk.

Security aspects, such as unauthorized access and manipulation of data within the network, can be addressed with the application of blockchain technology. Typical use cases for this technology are smart contracts which use computerised transaction protocols that execute the terms of a contract. With this type of technology, common contractual conditions and minimized exceptions, both malicious and accidental, can be achieved without the support of trusted intermediaries. As no human interaction is needed, the information flow risk can be significantly reduced. Other benefits of this technology are the reduction in fraud losses, arbitration and enforcement costs and other transaction costs. [33, 34]

Incorporating these use cases and potential benefits into the theoretical framework results in a comprehensive and detailed picture of how Big Data technologies can be applied in order to enhance risk management in supply networks:

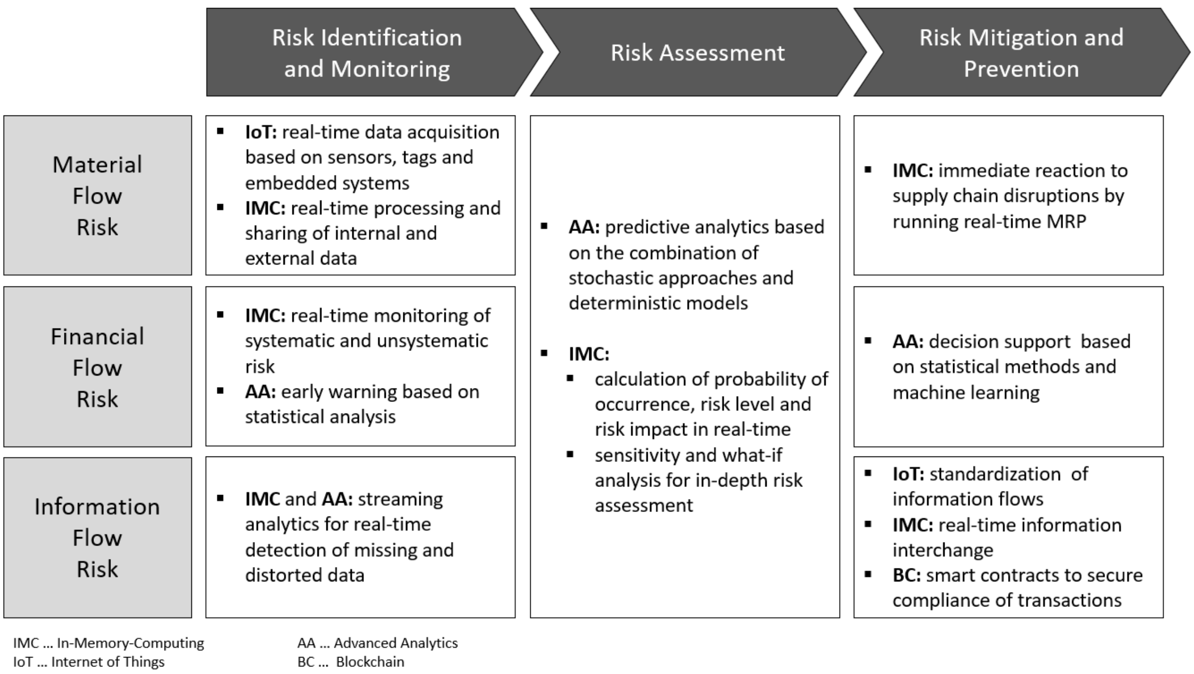

Fig. 3 Use cases for Big Data-enhanced risk management

7. Factors Influencing the Use of Big Data Technologies

Having discussed potential benefits of Big Data technologies in the area of risk management, factors that may influence or challenge the application of these technologies also need to be considered. Although the nature and extent of these factors are highly specific to the respective use case, some general aspects are discussed below as they are relevant for the implementation in business practice.

a) Big Data usually leads to a massive and continuous data flow. However, the purpose of Big Data-enhanced risk management is not to end up with the largest mass of data. Rather, it aims at utilizing data to improve and accelerate decisions as well as processes in the entire risk management cycle. Therefore, the company-specific objectives for Big Data-enhanced risk management have to be defined first. Subsequently, concrete use cases need to be derived which then determine the analytical requirements such as the amount and type of data and consequently, the required data sources. Also, technical aspects like data storage or questions like how often data should be loaded or whether it is necessary to have all data available in real time can be addressed adequately. [35]

b) Additionally, achieving and maintaining the quality of required data is becoming a constant challenge. This applies especially to external data which can be incorrect, inconsistent, redundant, distorted or biased. Traditionally, many companies have tried to improve data quality by establishing a golden record representing a single source of truth. However, most of the time this is too difficult or time-consuming in a Big Data environment. Thus, companies need to apply the notion of "fit for purpose" as the overarching principle with regards to data quality. Based on this principle, they can determine which data quality processes to run and whether to apply processes for data validation, enhancement or enrichment as well as the tools used in these processes (e.g. statistical methods or artificial intelligence techniques). [36]

c) Big Data-enhanced risk management potentially involves hundreds of variables and parameters. Incorporating all data into the driver-oriented predictive models for assessment, mitigation and prevention of risk would lead to overfitting and result in a bad prediction performance. A possible solution consists of applying sensitivity analysis in order to evaluate the susceptibility of the applied models and the resulting key performance indicators to changes in input parameters. Based on the results of the sensitivity analysis, the weighting factor for the most influential parameters is increased while irrelevant data is removed from the models, resulting in gradually refined models, and consequently in an enhanced quality and accuracy of the generated predictions. [37]

d) Costs are another factor influencing the successful application of the Big Data-enhanced risk management framework introduced in this paper. Today, the required technologies have reached a high degree of maturity and are commonly available at a constantly decreasing cost. Thus, the hardware and software components are no longer the main cost drivers. The major cost, however, is incurred by the operation and overall management or the integration of Big Data into an existing IT ecosystem. [38] Big Data has to be considered as an investment, therefore a critical analysis of its benefits and corresponding costs is crucial.

8. Conclusions

Rapid advancements in digital technologies have led to a constantly increasing rate of digitisation in supply chains, supporting the establishment of complex and highly interdependent supply networks. Besides the significant and widely undisputed advantages of such collaborative approaches, supply networks are exposed to a broad and growing range of internal and external risks. Thus, classical risk management approaches need to be enhanced. Big Data technologies can set the basis for innovative approaches. In this paper, we have examined the potential applications, benefits and major challenges of Big Data in the specific context of risk management. For this purpose, we developed a conceptual framework that addresses three major dimensions of Big Data-enhanced risk management: risk segments, risk management phases, and technologies.

A detailed analysis followed the phases of the risk management cycle. For each phase, possible application scenarios were identified and potential benefits were derived. Our analysis revealed that Big Data technologies, especially in-memory computing, advanced analytics, IoT-technologies, and blockchain have the potential for significant support for the entire risk management process. However, this requires the comprehensive application of these technologies throughout the entire network, which is still a long way to go in practice.

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