The Influence of Cognitive Biases on Supply Chain Risk Management in the Context of Digitalization Projects

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Abstract. Supply chains became more complex, widespread and vulnerable to disruptions over the past years, above all else due to an increasing digitalization in all industries. An effective supply chain risk management (SCRM) requires human decision-making in all phases, especially when it comes to manage the risks of digital applications. However, researchers in various disciplines showed that human decisions are often biased and hence not fully rational as typically assumed in SCRM research and practice. This leads to potential risks being missed completely, their likelihood being underestimated or to insufficient mitigation strategies being applied. We contribute to this issue by combining a systematic literature review on SCRM and cognitive biases (CB) with insights from practice. We present several use cases of digitalization projects in different industries to show the influence of CB on the risk identification, risk assessment and risk mitigation. Based on this, we provide first guidelines for theory and practice on how to consider CB in designing a successful SCRM and thus, how to make digitalized supply chains more resilient.

Keywords: Supply chain risk management · Cognitive biases · Digitalization

1 Introduction

Nowadays, digital applications and technological innovations transform the shape and functioning of supply chains and industrial operations [1]. However, human decision-making remains to be a crucial part of the digitalization, even though manual processes keep being automatized and physical interaction is increasingly replaced by digital exchange [2]. In fact, the functionality and efficiency of most digital solutions still depend strongly on the quality of human decision-making. This applies especially when it comes to managing new supply chain risks that accompany digital technologies in industrial areas of application. This is because the underlying basic activities of identifying, assessing, evaluating and mitigating are characterized by several main decisions, which are still to be made by humans.

M. Freitag et al. (Eds.): LDIC 2020, LNLO, pp. 137–147, 2020.
https://doi.org/10.1007/978-3-030-44783-0_13

An adequate supply chain risk management (SCRM) becomes indispensable especially for a successful implementation of new digital technologies, in order to exploit their full potentials without exposing operations to new risks. To support the implementation of an effective SCRM process, various models and frameworks have been proposed in literature over the years. However, these models disregard the human behavioral aspect of decision-making, which remains to be not only an inherent, but also crucial part of the SCRM in the context of digital applications.

Thus, effects influencing human decision-making are not only of interest for disciplines like psychology, but may also affect the quality of SCRM. In this context, research on the area of behavioral supply chain management has significantly increased over the last decade [3]. In addition, Tversky and Kahneman showed that human decisions are often biased, which means a systematic deviation from rational judgement. Decisions in the field of SCRM are characterized by complexity as well as uncertainty, and research has shown that under these framework conditions, humans systematically make wrong decisions [4]. The following example illustrates this connection, based on the prospect theory by [4]. There are two scenarios with different probabilities of occurrence and different durations of supply chain disruptions.

- *Option I:* With a 50% probability, the supply chain will be disrupted for 15 days.
- *Option II:* With a 90% probability, the supply chain will be disrupted for 5 days.

As people are loss-averse, supply chain risk managers will prefer Option I. In negative situations, humans prefer a higher but unsecure loss to a more likely, but lower loss. Regarding positive events, they behave contradictory as the following example demonstrates:

- *Option A:* With a 50% probability, the risk mitigation action will reduce the disruption by 15 days.
- *Option B:* With a 90% probability, the risk mitigation action will reduce the disruption by 5 days.

In case of positive events, humans are risk-averse. They prefer a lower but secure profit to a higher but unsecure benefit. Therefore, supply chain risk managers will most likely choose Option B.

This example illustrates how cognitive biases (CB) can affect the outcome and quality of SCRM substantially. Thus, we aim to answer the following research question: *How can the quality of SCRM in the context of digitalization projects be improved by reducing the distorting effects of CB on decision-making?*

Therefore, we combine a systematic literature review on SCRM and CB with insights from over 50 use cases on various digitalization projects from our research that reveal the influence of CB on the common main decision during the SCRM process. The use cases are based on the ‘platform Industry 4.0’, created and managed by the German Federal Ministry for Economic Affairs, which we examined further through phone interviews with responsible decision-makers [13]. After shedding light on the effects of CB, we determine first guidelines and recommendations for considering the human behavior for a successful SCRM in the context of digitalization projects.

2 Literature Review

2.1 Supply Chain Risk Management at Times of Digitalization

Over the past decades, the management of supply chain risks gained growing attention, since supply chains became more complex, widespread and vulnerable to disruptions. At the same time, digital technologies are increasingly applied to supply chains as well as operations, and raised manifold questions concerning new risk factors such as cyber risks, legal issues and the human-machine-relationship. Based on systematic literature reviews and experiences from practice, literature on SCRM provides numerous models and frameworks for types and sources of risks as well as mitigation strategies [5–7]. For example, Tummala and Schoenherr proposed a comprehensive 'Supply Chain Risk Management Process' framework for managers to run a standardized procedure [8]. Regardless of the consulted SCRM framework, the underlying, multi-step process is always characterized by three basic activities from a human decision-maker's perspective. At first, the risk manager has to identify the risks that are to be considered in the following process. Only risks that were identified initially can be further evaluated and finally mitigated or controlled. In the second step, the identified risks are assessed regarding both their likelihood and their severity, before both parameters are combined to evaluate the risk. Based on this, in the third step, the risk manager decides on which risk has to be mitigated and what mitigation strategies are suitable. Figure 1 illustrates how these basic activities are derived from the SCRM process framework by Tummala and Schoenherr, which is representative for similar SCRM frameworks in literature [9].

2.2 The Decision-Making Process and Cognitive Biases

The Decision-Making Process. Within the several phases of SCRM, several human decisions have to be made, such as decisions about adequate risk mitigation strategies. The process of decision-making has been investigated in several research areas, such as psychology, strategic and organizational management. Several models have been proposed that are mainly based on the work of Herbert A. Simon. According to [10] the decision-making process contains three phases. In the first 'Intelligence' phase, the decision-maker searches his environment for conditions calling for decision and gathers corresponding data. In the second 'Design' phase, a general action plan is defined, which contains several action alternatives and their expected outcomes. In the third 'Choice' phase, the decision-maker selects the best action alternative based on the evaluation of each alternative. Based on this general approach, one can identify several different main decision-making processes that are to be made during the three deducted phases of SCRM. Figure 1 illustrates, which decision-making processes correspond to each of the three SCRM phases.

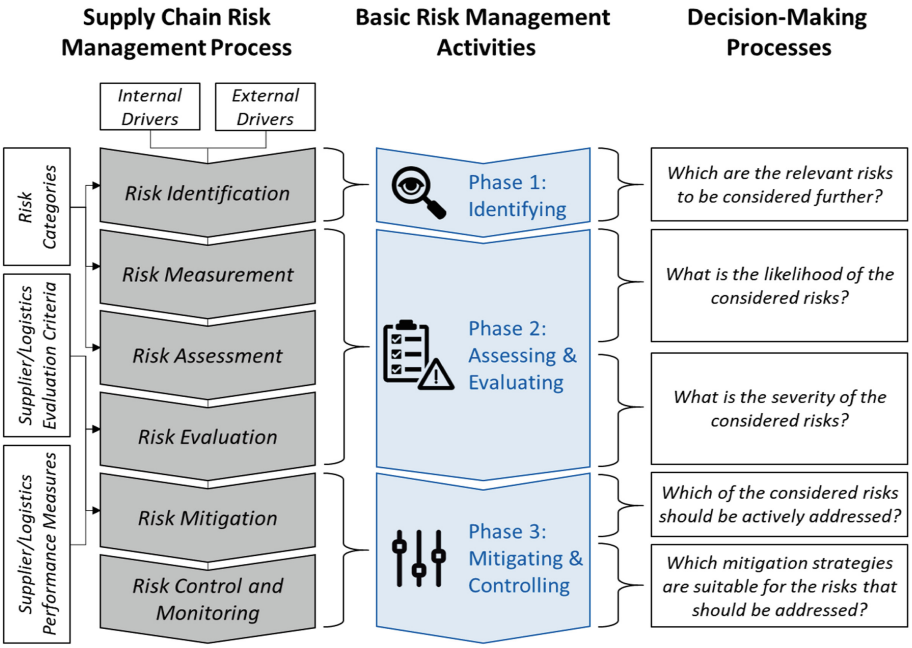

Fig. 1. Decision-making processes during SCRM process, based on Tummala and Schoenherr [8]

Cognitive Biases. Since SCRM decisions are very complex due to the increasing number of interlinkages between the involved parties, and often have to be made under time pressure, it is important to understand how these circumstances influences the decision-making process of risk managers. [4] showed that human decision-making is bounded rational, and introduced the term of *cognitive bias*. They state that humans taking decisions systematically go wrong, especially in complex and uncertain environments. Thus, human action and decision-making are often not completely rational, but distorted by the way humans perceive and experience their environment, by their experiences and their personal attitude. Arnott categorized these so-called CB into main categories, of which the following ones are most relevant for our approach [11]:

Memory Biases. Memory Biases summarize a group of CB related to the storage and availability of information. The Availability Heuristic describes the tendency of people to overestimate the likelihood of events for which they can easily restore the information [12]. As a result, people tend to overweight the outcome of the last decision as a basis for their decision-making in their current situation. The Imaginability Bias describes the fact that people assume an event more probable if it they can imagine it easily [4].

Statistical Biases. Statistical Biases describe the tendency to over- or underestimate certain statistical parameters. The Prospect Theory, also known as 'loss aversion',

describes the human tendency to value gains and losses differently. According to this theory, humans make decisions rather based on perceived gains instead of perceived losses [4].

Adjustment Biases. Adjustment Biases describe the human tendency to stick to the first available information or to a reference point when making decision. The Conservatism Bias is defined as the tendency to rely on an initially given information too heavily - which influences further evaluations [4].

Presentation Biases. Presentation Biases summarize a set of CB that influence humans in their decision-making by how information is being displayed. The Ambiguity Effect describes the human tendency to favor simple looking options and avoid options that seems to be complicated [14].

Situation Biases. Situation Biases describe the way a person responds to the general decision situation. The Complexity Effect describes that people are biased under time pressure, or when information overload occurs [11]. The Ostrich Effect describes the habit of people to ignore an obvious negative information [11]. The Bandwagon Effect describes the tendency to do things because many other people do the same [11].

Debiasing. Debiasing is a method to reduce or eliminate the influence of CB within the decision process. [16] propose three main categories with several sub-methods for an effective debiasing: Motivational, Cognitive and Technological. In addition, in the field of supply chain management, [15] recommend five categories for debiasing strategies: 'Decomposing/restructuring', 'Put yourself in the shoes of', 'Draw attention to alternative outcome', 'Devil´s advocate' and 'General bias awareness'. We combined both proposed categorizations and applied them to the SCRM phases in Sect. 4, in order to derive first practical recommendations.

Motivational. 'Incentives' and 'accountability' are the proposed techniques within this category. By offering decision-makers incentives based on the quality of their decisional outcome and keeping them responsible for the consequence of their decision, the decisional quality is believed to be enhanced.

Cognitive. [16] summarizes 'training' and 'considering the opposite' under this category as debiasing methods. This is quite similar to the proposed methods of [15] named as 'general bias awareness' and 'devil´s advocate'. A general awareness of the existence of CB can be viewed as an overall debiasing strategy. Even though the general understanding of the underlying influencing factors on decisions can improve decisional judgement quality, it cannot eliminate its emergence completely [15].

'Considering the Opposite' or 'Devil's Advocate'. This debiasing strategy focuses on the possible critique of other parties affected by the taken decision. Thereby, the 'devil's advocate' argues against the position of the decision-maker. Through this presentation of a formalized dissent, the decision-maker is forced to proof his decision and think about possible alternative outcomes [17]. In addition, the presented strategy of [15] 'draw attention to alternative outcome' can be summarized in this category.

Technological. One strategy in this category is *'group decision-making'*. Different experiences and opinions introduce new perspectives and lead to the group serving as a

validation and error-checking system that reduces individual errors [16]. In addition, the suggested method of [15], *'put yourself in the shoes of',* is much easier to achieve in a group.

3 Findings – Cognitive Biases' Influence on SCRM

As introduced before, different specific decisions have to be made during the three basic phases of the SCRM process, while decision-making is known to be distorted by several CB. At the same time, the digitalization confronts decision-makers with a huge amount of information about technologies and applications from various sources, as well as with new influencing factors concerning their decisions – making them vulnerable to several of the introduced CB. In order to understand the overall impact of CB on the SCRM process, it is necessary to evaluate what CB affect which decisions of the SCRM process. Therefore, we present the most relevant CB for each of the three phases and illustrate their effects with short cases and examples from our research.

3.1 Phase 1 – Identifying

Memory Biases – Availability Heuristic. The Availability Heuristic plays a crucial role when it comes to the initial, mere identification of risks. The evaluated use cases show that decision-makers are often influenced by the risk information they gathered during their initial recherché. Especially practitioners with a low technological know-how stick to popular and commonly known risks of digitalization when it comes to identifying relevant risk factors, instead of evaluating technologies and their concrete areas of application objectively. This holds true especially for the risk of directed cyber-attacks corresponding to popular hacker attacks on global companies or government agencies. Due to the huge public attention and the according reporting in media, practitioners can very easily restore this risk and ascribe it to almost any technology.

Situation Biases – Bandwagon Effect. The Bandwagon Effect is one of the most relevant CB in the context of Industry 4.0, since it is strongly characterized by trends and manifold reporting. Researchers, big players with great resources and smaller, but highly innovative companies continuously report about successful and rewarding Industry 4.0 use cases. Other companies feel the pressure to keep up with these innovators and often piggyback onto their exemplary, showcased applications and solutions. In this context, practitioners are fully taken up by understanding the technological applications, adapting them to their use case and tradeoff expected investment costs and potential benefits. Meanwhile, they overlook the dimension of new risks, consciously or unconsciously relying on the exemplary, external best practices.

Situation Biases – Ostrich Effect. Since most practitioners enters the phase of risk identification not until after the implementation, the high commitment leads to strong signs of the Ostrich effect. Especially due to high investment of different resources, the involved parties deny several risks they do not properly addressed. For example, the

omnipresent risk of unauthorized access through WLAN networks as a part of technological solutions is commonly not addressed before an implementation – and even if confronted with this risk, practitioners claim that their use case is uncritical since the transferred data would be useless for any kind of attacker. General mistrust and reservations of managers and/or operational employees towards innovative technologies intensify this effect frequently – since the responsible decision-makers constantly have to defend the application they suggested, supported and implemented (Table 1).

Table 1. Effects of CB on main decisions during the first phase of SCRM

Cognitive biases	Main decision(s) during the phase
	Which are the relevant risks to be considered further?
Memory biases	
- Availability heuristic	Considering only common and popular risks
Situation biases	
- Bandwagon effect	No or just rudimental consideration of risks due to blind trust in exemplary, external best practices
- Ostrich effect	Consciously ignoring particularly crucial and critical risks

3.2 Phase 2 – Assessing and Evaluating

Memory Biases – Imaginability Bias. When it comes to assessing the probability of the identified risks, practitioners assign high likelihoods to risks they are very familiar with. In practice, this commonly concerns risks associated with human failures, since practitioners often have a low knowhow regarding innovative technologies and therefore cannot easily imagine the associated risks. As a result, they underestimate the likelihood of digital risks, while overestimating the likelihood of the known, easily imaginable risk factors like hostile and refusing employees or human errors while handling new technologies. At the same time, when it comes to assessing the severity of known, easily imaginable risk, decision-makers trivialize and underestimate the potential consequences due to their experience and resulting confidence.

Adjustment Biases – Conservatism Bias. Regarding the assessment of technological risk, the use cases show that humans are often not willing to adjust their estimations over time. This cuts both ways and can result in overestimations as well as underestimations of certain risks. On the one hand, decision-makers do not update their assessments regarding the likelihood and/or severity of e.g. cyber risks over the years, even though technological progress improved or changed the security situation substantially. On the other hand, many practitioners still rate the quality of parts produced by additive manufacturing as too low for industrial usage – regardless of numerous examples of the recently highly increased quality and applicability of such parts (Table 2).

Table 2. Effects of CB on main decisions during the second phase of SCRM

Cognitive biases	Main decision(s) during the phase	
	What is the likelihood of the identified risks?	What is the severity of the identified risks?
Memory biases		
- Imaginability bias	Overestimation for known or easily imaginable risks	Underestimation for known or easily imaginable risks
Adjustment biases		
- Conservatism bias	Depends; rather overestimation for outdated risks	Depends

3.3 Phase 3 – Mitigating and Controlling

Statistical Biases – Prospect Theory. A general problem in human behavior during the final phase of risk mitigation is that mitigation measures create certain costs, while the eventual losses due to realized risks are uncertain regarding both their actual likelihood as well as the severity. The cases show that practitioners are often unwilling to apply mitigation measures for doubtlessly existing risks – and thereby rather accept uncertain, future costs of realized risks than certain, immediate costs of suitable measures. For example, most practitioners do not want to adapt the existing corporate IT security after integrating smartphones into certain operations via the company's WLAN, since they know about the sure effort and expenditures in money, time and personal. The corresponding risk of e.g. a cyber-attack on the other side remains a mere possibility with uncertain, but assumed low likelihood and a vague severity.

Situation Biases – Complexity Effect. The Complexity Effect influences decision-makers when it comes to handling risks of digital applications spontaneously and immediately. Firstly, digital applications are integrated into the infrastructure and the process landscape. Thus, when risks of these applications manifest, they are likely to affect the whole process chain and result in disruptions of operation. Since these are extremely costly in most industries, they create huge time pressure on the decision-makers and lead to biased decisions regarding risk mitigation. Secondly, manifested risks of digital applications are often complex and of technological nature, and thus overexert the decision-makers who are mostly not IT experts. This, equivalent to the aspect of disruptions of operations leads to biased and wrong decisions regarding risk mitigation (Table 3).

Table 3. Effects of CB on main decisions during the third phase of SCRM

Cognitive biases	Main decision(s) during the phase	
	Which risks should be actively addressed?	Which mitigation strategies are suitable for the risks to be addressed?
Statistical biases		
- Prospect theory	Solely mitigating risks with predefined, fixed costs	Denying mitigation strategies with fixed costs regardless of opportunity costs
Situation biases		
- Complexity effect	Wrong prioritization and/or choice of risks for mitigation	Choice of unsuitable or suboptimal mitigation strategies

4 Handling the Human Factor in SCRM Through Debiasing

After shedding light on the effects of CB on the different decisions during the SCRM process, we determine first guidelines and recommendations for considering the human behavior in this context. Therefore, we apply the established debiasing techniques derived in Sect. 2.2.

A general bias awareness serves as an overall debiasing strategy that should be implemented regardless of the actual phases of SCRM. This can be achieved through special trainings or online tutorials for supply chain risk managers, concerning the CB' effects. In the following, we deducted more specific debiasing methods for the three SCRM phases.

Phase 1 – Identifying. Contributing to the motivational strategies presented in Sect. 2.2, risk managers could be offered incentives based on the quality of their decisional outcome. In the context of SCRM, decision-makers could be involved in the result of their risk management by introducing rewards for failure-free hours of operation or cancelled rewards for interferences because of risks they overlooked during the identification phase. In addition, a standardized template could be used as a checklist to ensure a structured way to consider all relevant risk factors and influencing parameters while avoiding overlooking risks. This is especially useful in situations with information overload and the requirement for fast decisional outcome, to stay focused on the relevant information. Contributing to the influence of the anchoring effect and the availability heuristics, these techniques encourage risk managers to consider more influencing factors and not to stick to one information or parameter too heavily.

Phase 2 – Assessing and Evaluation. The methods 'considering the opposite' or 'devil´s advocate' can be applied for the phase of assessing and evaluating risks. This method forces risk managers to consider alternative possibilities and outcomes. Therefore, they have to explain and justify their estimations of likelihoods as well as severities and cannot hide behind mere numbers or scores. This method helps overcoming the most of the negative effects of CB as described in Sect. 3.

Phase 3 – Mitigating and Controlling. 'Group decision-making' is a suitable method to reduce the influence of CB in this phase. Instead of making one person responsible for one specific risk area, rather a group should be in charge for several risk areas. Different experiences and opinions introduce new perspectives, which can be helpful to evaluate different risk mitigation strategies. Since a group also functions as an error checking system, this method is also suitable for controlling the effectiveness of the chosen risk mitigation strategy. This also helps to overcome especially the overestimation of the ability to solve problems or searching for arguments which contribute to the own perception.

5 Conclusion

The aim of this paper was to answer the following research question: *How can the quality of SCRM in the context of digitalization projects be improved by reducing the distorting effects of CB on decision-making?* To achieve this, we combined the literature streams of SCRM and CB with practical insights to determine first recommendations for an effective SCRM, which considers aspects of human behavioral. Our presented cases of digitalization projects indeed showed strong evidence regarding an influencing effect of CB on decision-making. Since the necessary decisions differ between the three phases of SCRM, different CB become apparent and relevant during the respective phases as well. In connection to this, we also illustrated how the various biases distort the outcome of the individual SCRM phases. Finally, we provided first recommendations on how debiasing techniques may be used to mitigate the identified CB during the three phases of SCRM, in order to improve the overall decision-making process of risk managers.

Nevertheless, one should consider that our findings are based on expert interviews and therefore are influenced trough personal experiences. Moreover, it is important to understand that the classification of biases is not as concrete in practice as described in theory. Some of the CB overlap and often occur in several different situations as well. Therefore, some of our observations might be discarded, while others might be missing. Behavioral experiments based on a classification of different decision-making types therefore might be a further research field. These experiments could also be used to investigate the effectiveness of our proposed debiasing techniques in practice.

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