



SCHOOL OF ECONOMICS AND MANAGEMENT

Joining Forces with a Digital Twin

A study exploring the potential of a Digital Twin of an Organization in mitigating the impact of cognitive biases in strategic decision-making

By

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Master's Program in International Strategic Management

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**“There is no way in hell my mind
could be able to do all of that!”**

– Manager Nina, Company Alpha

Abstract

Title: Joining Forces with a Digital Twin: A study exploring the potential of a Digital Twin of an Organization in mitigating the impact of cognitive biases in strategic decision-making

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Purpose: The aim of this thesis is to investigate how a digital twin technology, specifically, a digital twin of an organization, can assist managers in making better decisions by mitigating the impact of cognitive biases.

Research Question: How can a digital twin technology help mitigate managers' cognitive biases when making strategic decisions to steer their company's innovation management?

Theoretical Foundation: This chapter provides an extensive literature review of key theoretical components, which helps set the stage for the reader. Beginning with an introduction of theory about the strategic decision-making process, followed by a brief outline of the implications of knowledge management on strategic decision-making in innovation management. It proceeds with situating the concept of digital twins of an organization in the literature on digital twins and describes the dominant characteristics. The chapter rounds off by introducing cognitive biases in information systems research and outlining the relevance of strategic decision-making.

Methodology: In order to fulfill the purpose of this thesis, a qualitative multiple-case study was conducted with an abductive research approach. The empirical data was collected through six online semi-structured interviews, two with experts and four with practitioners.

Conclusion: The findings show that a digital twin technology can help mitigate manager's cognitive biases when making decisions to steer their company's innovation management by (1) providing a holistic overview of elements and their interrelations, (2) presenting data and information in a visualized way, (3) forecasting solutions and outcomes using simulation, (4) capturing knowledge that was previously only in people's heads, and (5) providing a common database that allows speaking the same language. It is argued how these capabilities serve as enablers to better-informed strategic decision-making and how they can help counteract biases that have been identified to occur prior to having a digital twin of an organization available.

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Qendresa & Dennis

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List of Abbreviations

Abbreviation	Definition
DT	Digital Twin
DTO	Digital Twin of an Organization
IS	Information Systems
IT	Information Technology
SDM	Strategic Decision-making

1. Introduction

1.1. Background

Business as usual is said to be dead. Continued success no longer hinges on momentum (Hamel & Välikangas, 2003), as the environment in which today's businesses operate has become increasingly complex and uncertain (Schoemaker, Heaton & Teece, 2018). Given today's market expectations, competitive pressures, and the scope and speed of structural change, the ability to improve and change on a continuous basis has become an essential survival skill for organizations nowadays (Riss et al., 2020). Among others, Schilling (2017) explains that innovation is the primary engine of change, but without a full understanding of their business environment and what ought to be altered, companies will not be successful and risk losing ground to competitors. Fortunately, due to recent advances in technology, businesses now have access to a plethora of data (McAfee & Brynjolfsson, 2012; Parmar, Leiponen & Thomas, 2020) that can be utilized by managers to understand the business context and steer the innovation efforts in a strategic manner (Tan et al., 2015; Trabucchi & Buganza, 2019).

However, although the human mind packs spectacular power in its modest three-pound mass (Bazerman & Moore, 2012), it is widely recognized that this level of inflow of information is beyond a human's processing capacity (Molloy & Schwenk, 1995; Eppler & Mengis, 2004; Roetzel, 2019). Therefore, in an attempt to simplify information processing and compensate for potential gaps in knowledge when making decisions, our brains tend to fall back to cognitive shortcuts called "heuristics" (Hammond, Keeney & Raiffa, 1998; Russo & Schoemaker, 2002). Despite their usefulness, these shortcuts can, in turn, result in biased (i.e., flawed) decisions (Kahneman et al., 1982; Das & Teng, 1999). Worth noting is that this thinking technique does not require deliberate effort as it often happens naturally and subconsciously. As a result of this, decision-makers are not always aware when our way of thinking nudges us in a direction that no longer reflects reality (Hammond, Keeney & Raiffa, 1998). Managers are no exception and, therefore, not immune to these influences. Especially in today's dynamic age, where managers are facing information overload and ever more uncertainties, which in turn make it more

challenging to find the right information for their decision-making, the topic of cognitive biases becomes highly relevant (Acciarini, Brunetta & Boccardelli, 2020).

More specifically, as change has become the new imperative (Hamel & Välikangas, 2003), having the ability to determine the best possible decisions that can help the organization to best prepare for the future is essential (Riss et al., 2020; West et al., 2021). Oftentimes, organizations lack an overview model that indicates which data is relevant, which then results in a failure to deliver the desired business value (Gartner, 2021). However, one emerging opportunity from the increasing digitization is the phenomenon of “Digital “Twins” (DT) (Parmar, Leiponen & Thomas, 2020), which has arguably amplified the innovation quotient (Purdy et al., 2020; Raj & Evangeline, 2020; Qi et al., 2021). This concept has emerged recently as a means of addressing the challenges of information processing in modern digital transformation (Gyunam, Comuzzi & Van der Aalst, 2022). Briefly put, a DT is commonly summarized as a digital model designed to accurately mirror a physical object, process, or system (e.g., Gartner, 2021). Although the fundamental concept of a DT will be briefly explained in this thesis, this study will primarily focus on a so-called “Digital Twin of an Organization” (DTO). A DTO is a DT extended to the whole organization, mapping out all objects, processes, and their interrelations (Gartner, 2021; Gyunam, Comuzzi & Van der Aalst, 2022). In fact, Caporuscio et al. (2020) and Yan, Hong & Warren (2021) argue that a DTO is a viable option that lends itself to support and improve decision-making. More precisely, a DTO is said to allow decision-makers to gain a better understanding of the complexity of their business, as well as their direct and indirect interactions with a variety of parties and the environment. In turn, this comprehensive overview of all relevant variables aids in the assessment of the various trade-offs and costs associated with the various decision alternatives, allowing managers to optimize their decision process and achieve a better outcome (Caporuscio et al., 2020; Park & van der Aalst, 2021; Yan, Hong & Warren, 2021).

1.2. Problem Statement and Research Gap

Much has been written about decision-making and how increasing complexity in a company’s environment impacts the quality of decisions. Studies have shown how the interplay between a

given level of complexity, uncertainty, and the decision-making process promotes the occurrence of cognitive biases (Acciarini, Brunetta & Boccardelli, 2020). Research on the effects of using IT to improve decision-making under consideration of human cognitive constraints has been conducted since the mid-1990s (e.g., Keil et al., 1995; Molloy & Schwenk, 1995; Turpin & Plooy, 2004; Arnott, 2006; Ganju et al., 2020). Nonetheless, Godefroid et al. (2021) emphasized the broad prevailing interest in an IS context and the need for further research into this area, especially given that IS keeps evolving with new capabilities and features (e.g., a DT technology). Furthermore, a more diverse selection of the research subject, e.g., practitioners, has been identified as helpful (Godefroid et al., 2021). In fact, since the beginnings of research on cognitive biases in the 1970s (e.g., Tversky & Kahneman, 1974), researchers have mainly focused on studying students as the research subject.

At the same time, the volume of research on DT technology¹ has heavily increased in recent years (see, e.g., Liu et al., 2021). Studies have shown that DTs hold vast potential in aligning a company's innovation efforts and supporting SDM (West et al., 2021). However, only a few realizations and implementations of DTOs have been studied until today and these have only suggested that a DT technology theoretically holds the potential to mitigate the impact of cognitive biases on SDM (see, e.g., Yan, Hong & Warren, 2021). A further investigation into the capabilities of a DTO and its potential would thus enhance the understanding of how managers in practice can use it as part of their decision-making process to steer their innovation efforts more efficiently by mitigating the negative effects of biases. (Caporuscio et al., 2020; Parmar, Leiponen & Thomas, 2020; Park & van der Aalst, 2021; Gyunam, Comuzzi & Van der Aalst, 2022)

To summarize, it is generally assumed that DTs hold the potential in supporting managers to make better-informed decisions, meaning that they make decisions incorporating all relevant information. However, there seems to be a research gap in terms of a backlog in the academic literature on *how* DT technology in practice can help make better-informed decisions and mitigate cognitive biases managers encounter during the SDM process. Motivated by this

¹ For the purpose of this thesis, a DT or a DTO is considered an IS in its widest sense. IT constitutes an integral part of an IS and is therefore used somewhat interchangeably.

shortcoming, this study aims to tap into this opportunity by advancing the current understanding in the literature of this interplay from a *practitioner's* perspective.

1.3. Purpose and Research Question

Based on an extensive literature review and a qualitative research approach, the authors aim to investigate the implications of using a DT technology in SDM in innovation management under consideration of human cognitive biases. The purpose can be seen as twofold. Firstly, this thesis seeks to contribute to the identified literature gap in the previous section. Hence, the intended audience to be addressed is researchers in the field of strategic management and innovation management. Secondly, the practical value will be provided for practitioners that have not yet identified a technical solution to respond to the prevailing increase of complexity in their innovation management and to support the consecutive alignment of their company's innovation efforts. Further, due to the nature of the DT technology in use by the interview participants, the results are deemed particularly relevant for companies in designing, planning, or implementing a DT technology that considers the organization as a whole.

The identified problem and the purpose of this thesis lead to the following main research question (RQ), which ought to be answered in this thesis:

“How can a digital twin technology help mitigate managers' cognitive biases when making strategic decisions to steer their company's innovation management?”

1.4. Thesis Outline

This paper consists of six chapters which constitute the structure to examine the depicted topic in a logical manner. The first chapter is the introduction which provides the background for this thesis, problematization, purpose, RQ, and outline of this thesis. Following the introduction, chapter 2 presents a literature review on SDM, the implications of knowledge management in innovation management, DTs, and cognitive biases. Chapter 3 outlines and discusses the methodological approach that forms the basis for the implementation of this study. In this chapter, aspects such as research design, data collection, and data analysis process, as well as the

validity and reliability of the study, will be thoroughly explained. In chapter 4, the empirical findings from the practitioner and expert interviews are presented. Chapter 5 discusses the results and in light of the theoretical foundation to adequately address the RQ. In chapter 6, the RQ of the study is restated, and the theoretical and practical implications and limitations as well as proposals for future research are outlined. The final chapter lists the references that have been used throughout this thesis are listed in alphabetical order.

2. Theoretical Background

The following chapter provides an overview of the relevant literature and findings in the field of interest of this thesis. Further, the outlined theoretical aspects constitute the basis for discussing the empirical results in chapter 5. This chapter commences with an introduction of the theory about the SDM process on an individual level, highlights important aspects of information acquisition and usage, and is followed by a brief outline of how deliberate knowledge management supports SDM in innovation management. It continues with situating the concept of DTOs in the literature on DTs and describes the dominant characteristics. The third section introduces cognitive biases in IS research and outlines the relevance of SDM. The chapter concludes with a brief summary of the findings on cognitive biases in IS research.

2.1. The SDM Process on an Individual Level

This thesis is concerned with the cognitive process of SDM on an individual level, as opposed to group decision-making and organizational decision-making (Mintzberg, Raisinghani & Théorêt, 1976), in coherence with most previous published papers in the research field of interest (Fleischmann et al., 2014). To systematically approach the research of cognitive biases when making strategic decisions and how a DT can support mitigating them, the theoretical foundations of the decision-making process have to be examined first. As noted by Turpin & Plooy (2004) and Arnott (2006), the development of a system that supports decision-making requires an understanding of the process of decision-making itself.

SDM is described as the process of managers to decide about which fundamental actions ought to be taken and how resources are committed (Eisenhardt & Zbaracki, 1992; Das & Teng, 1999). According to Mintzberg, Raisinghani & Théorêt (1976), the basic structure of a decision-making process consists of a set of actions and routines and is impacted by different dynamic factors, such as interruptions and feedback delays. The authors suggest that the process can be broken down into three phases²: 1) Starting with the identification phase where a stimulus for action

² It is important to mention that Mintzberg, Raisinghani & Théorêt (1976) do not describe this process as rigid and the phases as strictly consecutive. Rather, the decision-making process is iterative, the phases are interrelated and can look different depending on the type of decision process.

(opportunities or challenges) is identified, and cause-effect relations are tried to be understood. 2) The process transitions to the development phase, during which one or multiple responses to the identified stimuli are searched and either modified or newly developed. 3) Consequently, the process ends with the selection phase, which means screening the alternatives and evaluating them, and finally selecting the action to be taken, respectively seeking approval from a higher hierarchical instance. (Mintzberg, Raisinghani & Théorêt, 1976) Barr, Stimpert & Huff (1992) focus on the crucial role of managers' mental model (further explained in chapter 2.3.1.) when making strategic decisions and propose three key managerial activities in a similar vein: (1) attention to environmental changes, (2) the interpretation of stimuli, and (3) the matching of perceived problems with solutions (Barr, Stimpert & Huff, 1992).

Das & Teng (1999) summarize that literature has identified various types of SDM processes that differ between the perspective taken and the paradigms that are deemed the most influential. According to Eisenhardt & Zbaracki (1992), three main paradigms in SDM exist, namely rationality and bounded rationality, politics and power, and garbage can. The focus of this thesis follows the paradigm of rational and bounded rationality, but a greater elaboration or comparison is omitted, as the purpose of this thesis does not cover how the effect of cognitive biases differ between the types of decision-making processes.

2.1.1. The Role of Information in the SDM Process

Mintzberg, Raisinghani & Théorêt (1976) further pointed out that during the SDM process, information is the crucial factor with its fundamental purpose to reduce uncertainty. On the role of information during the SDM process, Citroen (2011) remarked that, even though the importance of information is mentioned in literature on SDM, researchers often tend to ignore the quality, source, and use of information. A reason for that might be that "its accessibility is often taken for granted" (Citroen, 2011, p. 494). On the source of information, Frishammar (2003) distinguishes between external sources, where information is acquired from outside the organization, and internal sources, located within the organization and further split into personal and impersonal sources. Earlier researchers, such as Choo (1996), have already mentioned that well-informed decisions, especially those of strategic nature, require scanning an organization's

internal and external environment as a source of information. Regarding the importance of the information sources, managers have been found to rely far more on personal sources, i.e., coming from direct contact, probably through verbal communication with another person, than impersonal sources, i.e., in any written or non-verbal form (Frishammar, 2003).

Apart from acquiring knowledge from internal and external sources when formulating and implementing strategic decisions, managers tend to further rely on their values and experience (Acciarini, Brunetta & Boccardelli, 2020). In fact, with a growing number of years of experience, retrieving knowledge (knowing) becomes more effortless and automated, and the implicit knowledge becomes “tacit” (Bennett, 1998). Tacit knowledge is described as “an idiosyncratic, subjective, highly individualized store of knowledge and practical know-how gathered through years of experience and direct interaction within a domain” (Bennett, 1998, p. 590). The importance of tacit knowledge in combination with explicit knowledge in SDM has been shown by, e.g., Brockmann & Anthony (2002).

2.1.2. Knowledge Management Supporting SDM in Innovation Management

The background chapter has outlined why every company has the duty to ensure that continuous innovation is embedded in their strategy. However, to steer a company’s innovation efforts in the right direction, information serves as the foundation throughout the whole decision-making process (Frishammar, 2003). Without guiding the activities in compiling and processing external and internal knowledge to manage the inflow and outflow of information, innovation efforts are unlikely to be successful. Deliberate knowledge management is an essential prerequisite. (Frishammar et al., 2019) Acquiring information about the external environment supports managers in perceiving trends and challenges (Hambrick, 1982).

One example of the current innovation challenges (or trends) companies face, is the shift from inward-focused, product-centric innovation efforts towards acting more outward-focused and service-oriented, accompanied by digitalization (Brynjolfsson & McAfee, 2014; Cenamor, Rönnerberg Sjödin & Parida, 2017; Frishammar et al., 2019). Managers have to be aware of such

trends; otherwise, they risk their company's competitiveness by either missing out on opportunities or underestimating the challenges. But responding to trends and generating alternative actions becomes challenging given the many variables and actors, resulting in a high level of uncertainty and complexity. (Frishammar et al., 2019) To draw linkages between variables and understand their interrelationships, managers rely all too often on their mental model stemming from experiences and their intuition to make sense of a situation (Tan & Platts, 2003). The potential pitfalls of this are the central aspect of chapter 2.3.

In supplementing an effective and deliberate knowledge management approach to strategically respond to the innovation challenges, knowledge visualization has been found to provide decision-makers the opportunity to better understand the complexity of their business, processes, and the interrelationships between different parties and the environment (Tan & Platts, 2003; Eppler & Platts, 2009). It holds the potential to make complex circumstances better understandable and "helps individuals in assessing, structuring and managing their knowledge." (Tergan, Keller & Burkhard, 2006, p.168). In search for tools among the manifold IT systems available to support strategic decisions, DT technology has been found to offer a unique opportunity to visualize and display all organizational data in a holistic way and further simulate changes affecting the data (Yan, Hong & Warren, 2021), which will further be elaborated on in the next section.

2.2. DTs in Literature

2.2.1. DTs: Definition and Relevance

DTs are among the latest buzzwords in the IT space. They are part of the digital theme that describes an ever-increasing merger of the digital and physical worlds (Gartner, 2021), which is an unavoidable trend in order to deal with the market's growing complexities and high demands (Liu et al., 2021). Fundamentally, a DT serves to virtually accurately mirror the properties and states, including shape, position, gesture, status, and motion of a complex real-life object (e.g., product, process, and system) in real-time (Parmar, Leiponen & Thomas, 2020; Yan, Hong & Warren, 2021; Park & van der Aalst, 2021). The concept of a DT originally dates back to the

National Aeronautics and Space Administration (NASA) Apollo program in the 1970s, where it was used to simulate the space journey before departure (Rosen et al., 2015; Negri, Fumagalli & Macchi, 2017; Miskins, 2019). Ever since, the definitions of a DT have been continuously evolving, covering a broader range of applications and domains. The by-product of such widespread usage is that the concept has been interpreted in a variety of ways (Jiang et al., 2021). Though the literal meaning of DT seems simple at first, the definition has been a subject of debate. In fact, a literature review of what constitutes a DT reveals the diffuseness of the concept as its definition depends on the applications in disparate disciplines. (Tao et al., 2019; Sharma et al., 2020; Hu et al., 2021)

Nevertheless, the concept of a DT continues to spread its wings wider as the technology has turned out to be a strategic asset able to solve many company conundrums (Raj & Surianarayanan, 2020). In the era of Industry 4.0³, where many industries are undergoing digital transformations, a DT is nowadays viewed as a critical component in gaining a competitive advantage over competitors (Kritzinger et al., 2018; Fuller et al., 2020; Singh et al., 2021). Generally, the value a DT can bring to any sector, whether that is in terms of performance, cost-savings, optimizations, efficiencies, or economic benefits, is frequently encapsulated as “indisputable” (Tao, Zhang & Nee, 2019; Singh et al., 2021). Jiang et al. (2021, p.1) go as far as to call it “the innovation backbone of the future”. It is due to its far-reaching application potential that DTs have recently become a popular and commonly discussed topic, both in industry and academia (Jiang et al., 2021). The main applications of the technology include, inter alia, monitoring (Shao et al., 2019; Jiang et al., 2021; Hou et al., 2021), simulation (Boschert & Rosen, 2016), designing/planning (Kritzinger et al., 2018; Shao et al., 2019), forecasting (Wang, Wang & Liu, 2020; Fujii et al., 2022), optimization (Tao & Zhang, 2017), safety (Hou et al., 2021; Jiang et al., 2021), decision-making (Jeong, Flores-García & Wiktorsson, 2020; West et al., 2021), predictive maintenance (Anderl et al., 2018; Singh et al., 2021), prototype testing (Sharma et al., 2020) and training (Singh et al., 2021). As the DT paradigm continues to acquire a lot of mind and market shares, it is increasingly percolating to additional industry domains.

³ Industry 4.0 refers to a new phase in the industrial revolution, i.e., the fourth industrial revolution, where emphasis is on, among others, interconnectivity, AI and automation.

2.2.2. The Building Blocks & Capabilities of a DT

Although the scope, size, and speed of DTs are bound to vary, researchers agree that a DT contains three fundamental elements: a physical part, a virtual representation, and connections (bi-directional) of data and information that tie these parts together (e.g., Tao & Zhang, 2017; Fuller et al., 2020; Agnusdei, Elia & Gnoni, 2021). Considering the importance given to data in this thesis and the fact that data is viewed as a strategically vital resource in society (Xue, 2017), this latter element requires further elaboration. In fact, an essential cornerstone of all DTs (no matter shape or form) is data (Bordeleau et al., 2020; Liu et al., 2021; Resman et al., 2021). Based on the continuous real-time data⁴ acquired about the physical entity, a DT evolves synchronized alongside its physical counterpart (Resman et al., 2021) as it transforms the data into actionable insights (Boschert & Rosen, 2016). The data is often multi-structured and derived from multiple data sources (Agnusdei, Elia & Gnoni, 2021). Together, these building blocks enable a DT to create a picture of the complex connections and relationships between various components in the current state and to experiment with different hitherto unknown future scenarios (Raj & Surianarayanan, 2020). This holistic, up-to-date, and enriched view of the physical entity is what makes the DT so unique and useful (Riss et al., 2020). A DT further helps guide managerial attention to where intervention might be required (Becker & Pentland, 2022). What is more, the DT also allows for the integration of explicit and tacit knowledge within a system, which is a critical aspect of knowledge management due to information only being truly valuable when it is relevant to the individual actor (Meierhofer et al., 2021). These capabilities of a DT have, in turn, been shown to enhance a manager's decision-making (West et al., 2021).

2.2.3. A “Digital Twin of an Organization”

As DTs have become more mainstream, it has become increasingly clear that anything can have a DT. A DT does not only mirror the properties of a physical object but it can also be extended to more complex entities. In fact, even businesses and organizations are developing enterprise-level DTs (Raj & Surianarayanan, 2020). Coined by Gartner (2019), an enterprise-level DT is

⁴ Note that this can be on a daily, monthly or yearly basis - it depends on the application of the digital twin technology.

commonly referred to as a “Digital Twin of an Organization” (DTO). The concept of DTOs has recently emerged as a means of addressing the challenges of information processing in modern digital transformation (Gyunam, Comuzzi & Van der Aalst, 2022). Nowadays, companies must be able to respond quickly and nimbly to changing environments in order to remain competitive, and having situational awareness is a prerequisite (Park & van der Aalst, 2021). This awareness is not restricted to the external environment but includes an understanding of all the elements of an organization and how they relate to each other (Riss et al., 2020). Thus, a DTO is posed as a proper instrument for increasing a company’s situational awareness, and this improved insight can, in turn, be leveraged to derive better-informed decisions (Gartner, 2021).

Gartner (2021) refers to the DTO as a GPS that can guide a given organization to its desired destination. They explain that, unlike existing methodologies, a DTO provides a comprehensive insight into the network of a company’s business operations, showing the relationships of all elements (including physical, software, and human elements). This provides the necessary visibility, guidance, and monitoring, allowing an organization to adapt to a rapidly changing environment (Riss et al., 2020; Gartner, 2021). This is especially valuable for managers as the network is highly complex and interconnected and given the human difficulty in comprehending complex systems (Becker & Pentland, 2022). Along the lines of Gartner (2021), Caporuscio et al. (2020) also pose that a DTO allows the continuous assessment and optimization of the organization and is helpful for achieving organization-environment alignment. This is in large part because the DTO provides managers a consolidated view of the factors influencing a given decision, as well as a prediction of the decision’s outcome (Caporuscio et al., 2020). Riss et al., (2020, p.37) summarize this holistic and simulation capability by stating that it prevents the user “from not seeing the forest for the trees”.

2.3. Introducing Cognitive Biases in SDM in an IS Research Context

2.3.1. The Role of Human Cognition in SDM

Complexity of strategic decisions results from imperfect knowledge about choices that are important to a company’s resource allocation, for which no predetermined set of responses exists

in the organization (Mintzberg, Raisinghani & Théorêt, 1976). Mintzberg (1973) further states that the quality (or effectiveness) of a knowledge-based decision largely depends on the manager's mental model, which is constrained by human bounded rationality. Mental models can be seen as the mental concepts humans use to make sense of a situation or their environment (Barr, Stimpert & Huff, 1992; Tan & Platts, 2003). Those models map one's understanding of interrelated information and help to deal with the abundance of new information (or stimuli) available (Kiesler & Sproull, 1982). Barr, Stimpert & Huff (1992) have shown that the ability of an organization to respond to environmental changes correlates with managers' mental model to develop new beliefs about cause and effect relations. Noticing and constructing the meaning of changes that require taking strategic actions is deemed crucial in managers' behavior (Kiesler & Sproull, 1982). The authors also refer to this cognitive process as "problem sensing".

Simon (1955) developed the theory of bounded rationality which describes that humans have only a limited set of information available when making decisions. They, therefore, have to "satisfice" instead of maximizing, which constitutes a trade-off between an optimal and a good-enough decision (Simon, 1955). Dealing with complexity in the face of the limitations of human intellectual capacities requires "simplified models that capture the main features of a problem without capturing all its complexities" (March & Simon, 1958, p.169). Simplified, conceptual models are a result of decision-makers relying on different problem-solving shortcuts described as the act of satisficing. To be able to approach a complex and unstructured situation, decision-makers parse them into familiar and structural elements. (Mintzberg, Raisinghani & Théorêt, 1976) By doing so, humans rely on unconscious routines when processing information, called judgemental heuristics, which are generally purposeful but prone to flaws. These flaws are referred to as "cognitive biases", leading to suboptimal decisions. (Hammond, Keeney & Raiffa, 1998)

Cognitive biases have been found to be "systematically associated with strategic decision-making processes" (Das & Teng, 1999, p.757). The degree to which they apply varies between individuals but shows the direct effect of biases on the decision-making outcome (Busenitz & Barney, 1997). Mintzberg, Raisinghani & Théorêt (1976) highlighted the risk of cognitive biases

to be particularly high during the identification phase of a decision-making process due to the higher potential to suffer from information overload. Acciarini, Brunetta & Boccardelli (2020) attribute the risk to the analysis of information in general, e.g., when trying to detect environmental trends.

2.3.2. Cognitive Biases in IS Research

Seminal work in the exploration of heuristics and biases in decision-making has been conducted by, inter alia, Tversky & Kahneman (1973) and (1974). In their early work, Tversky and Kahneman introduced three initial types of cognitive heuristics that may lead to different biases: availability heuristics, representativeness heuristics, and anchoring and adjustment heuristics. When examining the occurrence of biases, researchers intend to measure human decision-making proficiency by supposing a bounded rationality behavior and comparing it to a normative view of rationality. (Busenitz & Barney, 1997; Turpin & Plooy, 2004; Ceschi et al., 2019)

Fleischmann et al. (2014), who compiled the first overview of research that has been published in the field of cognitive biases in IS research, show that since Tversky and Kahneman introduced the three initial heuristics leading to biases, various additional biases have been discovered and described. The total number of different cognitive biases identified in the IS research context ranges up to 46, while some have been researched more extensively (e.g., framing or anchoring bias), and others have received only little attention so far (e.g., exponential forecast or cultural bias) (Fleischmann et al., 2014). Fleischmann et al. (2014), as well as Godefroid et al. (2021), highlighted the need for an IS specific research approach but also remarked on the disconnectivity and inconsistencies in previous studies regarding the use of methodologies, theory, terminology, taxonomy, and measuring, i.e., inconsistent use of variables, which is true for the general research on heuristics and biases (Arnott, 2006; Ceschi et al., 2019). However, the volume of the literature shows the vast promising potential for improvements in decision-making using information systems (see also, e.g., Browne & Parsons (2012)).

To allow a certain level of depth in the analysis in chapter 5, to account for the relevance of the biases in the IS literature, and given the time constraint, it was decided to focus on the biases that

were found to be the most discussed in the literature. For the purpose of this thesis, the biases that were found to be discussed in a minimum of four previous studies according to the literature review by Fleischmann et al. (2014) were included. Hereafter, an overview of the biases and a brief description is given.

Framing (n=14): The way a problem is framed profoundly impacts the decision made (see, e.g., Tversky & Kahneman (1981). Two different framing traps have been discovered: 1) Frames as Gains vs. Losses, where “people are risk-averse if a problem is posed in terms of gains [...] but risk-seeking when a problem is posed in terms of avoiding losses” (Hammond, Keeney & Raiffa, 1998, p. 54) and 2) Framing under a different reference point (Hammond, Keeney & Raiffa, 1998).

Anchoring (n=10): In a situation where a decision has to be made, for example, estimating a total number or the probability of an event to occur, the human mind gives proportionally much weight to a piece of information that has been received first (see, e.g., Tversky & Kahneman (1974)).

Negativity bias (n=7): Information, situations, events, or even words evaluated in a negative way in the past impact decisions about future actions disproportionately higher than if they were perceived in a positive way (see, e.g., Luo et al. (2010)).

Sunk cost fallacy (n=7): If an investment in any kind of endeavor has been made, decision-makers are more likely to pursue this endeavor over a new one, irrespective of the cost-benefit ratio (see, e.g., Arkes & Blumer (1985)).

Overconfidence (n=6): People who believe to be experts in a certain subject are more likely to express certainty and overestimate the correctness of their answers, even when facing a high level of uncertainty (see, e.g., Bradley, 1981)).

Confirmation bias (n=5): Describes the tendency to seek or interpret information that confirms one’s belief or values, especially in ambiguous situations or in connection with a strong desire for a certain outcome. Contrary information is more likely to be disregarded. (see, e.g., Mahoney, 1977))

Halo effect (n=4): An attribute or trait that was first connected to a person tends to affect one’s beliefs about the person in general and is also transferred to other situations or areas (see, e.g.,

Kahneman (2013)).

Availability bias (n=4): The easier information is recalled, the more likely one thinks that it reflects the truth and is disproportionately higher weighted when considering alternatives (see, e.g., (Tversky & Kahneman, 1973)).

Status-quo bias (n=4): Describes the preference to stick to the current state, as the potential losses are higher weighted than the potential gains (see, e.g., Kahneman, Knetsch & Thaler, (1991)). Changing the status quo puts us in a potential situation of risk, whereas the human brain seeks to avoid that (Hammond, Keeney & Raiffa, 1998).

Herding (n=4): An individual who is influenced by the decision of others (see, e.g., Lee & Lee's (2012) study about herding behavior in the online P2P lending market).

Reactance (n=4): When restricted in their choice, people react differently and are more likely to react in a negative way (Murray & Häubl, 2011).

Excluded was **Irrational escalation (n=4)** as the argumentation of its occurrence is strongly connected to other biases such as the sunk cost fallacy and the framing effect (see, e.g., Desai & Chulkov (2011)), which have already been covered.

It should be finally noted that the focus on cognitive biases in this thesis does not imply that biases are the only nor the most dominant factor impacting the quality of strategic decisions. Various other factors, such as but not limited to organizational policies, demographic characteristics of the top-management team, age of the decision-makers, or team dynamics, have been found to have a profound impact as well (Acciarini, Brunetta & Boccadelli, 2020).

2.4. IT Usage to Mitigate Cognitive Biases

As priorly mentioned, human cognitive limitations and the need for simplification of complex issues lead humans to be imperfectly rational or boundedly rational (March & Simon, 1958). An alternative to trying to rationalize decision-makers is that processes and applications can be designed and programmed to accommodate rationality (Isenberg, 1984).

Early research on decision-making and the effects of using information technology as a supporting tool to mitigate human cognitive weaknesses, e.g., mitigating biases, has been conducted by, among others, Molloy & Schwenk (1995). Information technology was assumed to be supportive in processing large amounts of data to account for potential weaknesses in managers' mental models. Further, it ought to expand human limits when it comes to problem-related communication. Their findings support the assumption that "the use of information technology does improve both the efficiency and, more importantly, the effectiveness of the decision-making process" (Molloy & Schwenk, 1995, p. 301).

Especially the knowledge visualization capability of an IT system is described as a way to address the issue of processing large amounts of data. Information represented in a visualized way has been proven to be supportive in transferring knowledge, allowing a common language to share expertise. This further provides different actors to have a common ground to outline a problem, targeting for example the framing biases that might occur without such a support tool. (Yan, Hong & Warren, 2021) Visual representation of data can support managers in detecting patterns that would otherwise be harder to detect through, e.g., statistical methods (Lurie & Mason, 2007)

In turn, research has also shown that the usage of IS to support SDM can reinforce existing biases as well as introduce new ones. The extent seems to vary depending on the design, maintenance, and usage of an IS system. (Turpin & Plooy, 2004) Due to technology becoming more involved in the decision-making process, users might be influenced by factors such as a positive or negative perceived user experience, an overreliance on the automatization of processes, or other emotional influences (Darioshi & Lahav, 2021). Further, depending on the level of advancement or unfamiliarity of technology, decision-makers can become overly positive about its potential (Clark, Robert & Hampton, 2016). Looking at the specific capabilities of an IT system, such as the aforementioned capability to present data in a visualized way, one has to be aware that, e.g., highlighting irrelevant data might lead to flawed pattern recognition and decisions. (Lurie & Mason, 2007) Turpin and Plooy concluded that reducing biases "requires

innovative thinking on the way information is represented and the way human decision-making processes are supported” (Turpin & Plooy, 2004, p. 740).

3. Methodology

This chapter outlines the methodology process chosen to address the research question and purpose of this study. First, the choice of research method and the design of the research are explained and motivated. Second, the sampling process, including the selection of cases and interviewees, is elaborated and justified. Third, the interview process, including format, interview participants, and transcription of interviews, is stated and motivated. This part is followed by an explanation of the data analysis process. Finally, the chapter ends with a methodological discussion that reflects upon the ethical considerations and trustworthiness of this study's empirical results and findings.

3.1. Choice of Method

3.1.1. Research Paradigm

This study intends to detail and gain a deeper understanding of managers' decision-making in consideration of cognitive biases *ex post* a DT implementation. Given the focus on human behavior, the *epistemology* of this study is naturally *interpretive* in nature (Bell, Bryman & Harley, 2018).

Furthermore, the thesis authors do not know in advance how this reality is shaped, nor that there is an absolute truth, as it is dependent on how the managers at the case company perceive this reality. On this basis, the authors claim that the study has a *constructivist ontological* view of science as the studied managers only reflect one version of reality (Creswell & Creswell, 2018). The researchers' role is thus to reconstruct this reality through the interpretation of the verbal meanings and opinions given by the managers.

3.1.2. A Qualitative Approach

Quantitative research provides a more static view of reality than qualitative research (Bell, Bryman & Harley, 2018). The quantitative approach is also often criticized for being too broad, as it does not provide depth to the information gathered (Jacobsen, 2002). On the contrary, this study's aim relies on the gathering of rich and deep human-focused data, which is best

accomplished by giving prominence to words over numbers (Creswell & Creswell, 2018). In consideration of both the study's aim and the limitations inherent in a quantitative approach, this study, therefore, employs a qualitative research method. More specifically, this approach was deemed appropriate and advantageous as it offers tools to capture the complexity and contradiction of SDM behavior (Blumer, 1956). It is further appropriate for studying a phenomenon that is evolving and changing, as in this case (Gephart, 2004). The thesis' research paradigm is also typical of a qualitative study, further confirming the congruency of the chosen method of inquiry (Bell, Bryman & Harley, 2018).

3.1.3. Case Study Design

As the thesis writers sought to study a complex phenomenon within its context, a case-study methodology was undertaken. In addition, Fleischmann et al. (2014) metastudy shows that the most utilized research methods in researching cognitive challenges in an IS context differ are laboratory experiments or field experiments. Of lower utilization but still deemed appropriate are case studies. This fact lends credence to the design choice. One of the great strengths of a case study approach is that it allows for aspect richness (Yin, 2018). Furthermore, a multiple-case study was chosen over a single-case study. The reasons for this are twofold. The main argument in favor of this design is that it would allow the researchers to understand the phenomenon to a greater extent by comparing and/or contrasting the findings deriving from each of the cases (Bell, Bryman & Harley, 2018; Creswell & Creswell, 2018). The comparative design, in turn, strengthened the generalizability of the findings as they were not based on a single case exploration. The second reason is that by comparing several cases, the researchers would be better able to determine the conditions under which the theoretical foundation explored in chapter 2 would or would not hold (Yin, 1984; Eisenhardt, 1989; Bell, Bryman & Harley, 2018).

Despite the many benefits of the multiple case study approach, it is critical to recognize its limitations. First, the researchers acknowledge that this choice might have negatively affected the depth of results (Yin, 2018). Second, multiple-case studies are often accused of lack of rigor as there are no specific procedures for investigators to follow, which makes it easier for ambiguous evidence or biased viewpoints to influence the direction of the findings and conclusions (Yin,

2018). Nevertheless, the authors argue the possibilities that come with multiple cases outweigh the possible limitations. In this study, in total, four cases were studied and compared.

3.1.4. An Abductive Process

The abductive process was chosen to overcome some of the limitations inherent in the deductive or inductive processes. For instance, by not being guided by a hypothesis as in a deductive approach, the iterative process that followed allowed for the continuous discovery of new knowledge (i.e., explanations, topics, patterns) (Wheeldon, 2010). The abductive approach also enabled an iterative development of the research question and theoretical background, making it more accurate and concise, as well as more closely linked to the empirical findings that emerged (Creswell & Creswell, 2018). The benefit of using such an iterative approach is that it allows for both the confirmation of existing theory and the establishment of new theory (Bell, Bryman & Harley, 2018). Overall, the broad scope for interpretation provided by this approach was especially important for the researchers who constructed and interpreted the interviews.

3.2. Choice of Sample

3.2.1. Research Company

The chosen research company, Ortelius, is a DT software services company based in Malmö, Sweden. Since its inception in the late 1990s, the company has assisted global corporations in the digitization of their operations, converting their intellectual capital into business benefits, competitive advantage, and profitability. This research company was chosen due to its expertise within DT technology, and out of convenience as the thesis writers had access to their contact details through a professor. It is worth noting that Ortelius has developed the DTO that they provide themselves. Together with company representatives, the researchers of this study decided upon a range of client companies that would later be the main focus of this study.

3.2.2. Sampling Technique

To continue where the preceding paragraph left off, a convenience sampling method where the selection of units of analysis (i.e., clients) was based on the ready availability (Creswell & Creswell, 2018) was chosen. The researchers requested and received a list of suitable and available interviewees totaling five candidates. However, the third interviewee did not end up participating in this study. Of the four candidates that were interviewed, two of them were from the same company, and the remaining two candidates were from separate companies. This availability was primarily influenced by the accessibility to the client companies. Given that convenience samples tend to be more tainted by bias (Creswell & Creswell, 2018), the researchers took special care to ensure that there was a fit between the study's purpose and the subsequent client companies. The selection of study participants was especially important to accurately represent the phenomenon of interest and to ensure the credibility of the study's final results. Accordingly, a number of different criteria were established to ensure that emphasis was on those participants who could contribute relevant information to the study. Specifically, the analytical criteria for sampling were: (1) that the client companies had implemented a DTO solution and (2) that the interviewed manager used it to support the SDM process in innovation management.

Furthermore, because *saturation* was achieved, the sample size was assumed to be adequate. Saturation was demonstrated by the fact that no new areas of analysis or additional information were observed during the last interview session. "This is when you have an adequate sample" according to Creswell & Creswell (2018, p.262). While it was not necessary for this thesis, the authors were nevertheless prepared to add additional clients if it was deemed necessary to achieve saturation.

3.3. Interview Process

3.3.1. Semi-structured Interviews

Interviewing is the most common data collection format in qualitative studies (Jamshed, 2014), and it was used in this study as well. This format allowed for a contextualized account of the experiences of the respondents and minimized the potential risk of misunderstanding on the part of the interviewee that is common in, for instance, survey research. Naturally, not everyone is as articulate and perceptive verbally as others are, but the researchers were careful to ask for clarification when necessary. Also, since the findings are based on the retrospective recollections of the people involved in the phenomenon under study, there is a potential risk of memory distortion and memory failure (Mintzberg, Raisinghani & Théorêt, 1976). Nonetheless, the authors still argue that this risk was minimized by challenging the interviewees' answers and asking probing questions to help the interviewees think about examples from different angles.

Creswell & Creswell (2018) state that a critical step in an interview is to set the interviewee at ease. Accordingly, the thesis authors were careful to create a safe environment for discussion prior to the actual interview by initially asking a number of neutral and uncontroversial questions that were not directly related to the purpose of the interview. This approach was perceived to ease the transition to the actual research-focused questions.

Since the study's research questions required that respondents speak relatively freely about the topic at hand, it was decided that *semi-structured* interviews were appropriate. Furthermore, interviews with two types of respondents were conducted: managers at the consultancy firm Ortelius and top-level managers at its client companies. In total, six semi-structured interviews (two expert interviews and four client interviews) were conducted within a time interval of 53:50:00 - 80:50:00 minutes. The time and length of the interviews varied with respect to the respondent's availability and/or the depth of their answers.

The respondents were interviewed according to a predetermined interview guide. More precisely, two different interview guides were created: one for the research company and one for the clients.

As the interviews were of a semi-structured nature, no strict questions were asked; instead, different themes followed with broad, open-ended questions. The prepared questions served rather as a guide throughout the sessions and were supplemented with probing questions depending on the direction of the discussion to ensure that the conversation was relevant to the research topic. Appendix I and II presents a list of key questions in both interview guides that triggered the discussions. This approach was advantageous as it increased the depth of the interview by giving the interviewees significant freedom to build and extend the discussion (Bell, Bryman & Harley, 2018). Thus, deviating from the posed questions allowed for the exploration of particularly intriguing topics which emerged naturally. For the client interviews, a total of four initial subjects were prepared with associated broad questions that were linked to the main purpose of the study. This was done to allow for easier analysis later. See Appendix II for the outline of the interview topics. Regarding the expert interviews, the researchers felt that there was no need to divide the interview questions into different themes as the sample of expert interviews was comparatively very small.

All interviews were conducted over either Teams or Zoom, which are two different video conference platforms. The respondents were asked their preferred platform, hence decreasing the risk of, for instance, loss of time. The choice of online interviewing was a mutual decision between the thesis authors and the interviewees, and it was especially fitting since the sample was geographically dispersed. At the same time, Bell, Bryman & Harley (2018) note that the length of online interviews is unlikely to be sustainable for long in comparison to personal interviews. Curasi (2001) also suggests that it may be harder to establish and maintain personal relationships with the respondents over video interviews. However, the researchers did not observe these delimitations during the interview sessions. By asking probing questions, the researchers extended the duration of the interview and the acquired data that fulfilled the purpose of this study and answered our research questions (Creswell & Creswell, 2018). In addition, both thesis authors were present and equally involved in all interviews. This was considered desirable as the researchers could follow up on, support, and complement each other's questions.

Finally, all respondents were provided with a credible rationale for the research. This introductory rationale was emailed beforehand and reiterated during the interview. It was constructed based on Bryman & Bell (2011, p.211) tips of issues to include in such a statement. See Appendix III for the introductory statement in full.

3.3.2. Interview Participants

According to Solvang & Holme (1997), when choosing respondents, it is of utmost importance to focus on the individuals who possess information that is relevant to the study and can contribute useful information. The primary unit of measurement and analysis in this study is on an individual level. The researchers chose to interview managers at Ortelius’ clients who are well acquainted with Ortelius’ DTO product and have the authority to make strategic decisions that affect their company’s innovation efforts. In this way, it was ensured that appropriate information was collected. Following a similar line of reasoning, it was also important to the researchers that the consultants at Ortelius held the needed expertise and were deeply knowledgeable about the properties of the DTO and its potential. The information provided by these consultants⁵ was later used to confirm and/or extend the practitioner’s answers by giving alternative explanations and additional aspects of the phenomenon.

All client companies and their respective manager representative(s) have been assigned fictitious names for anonymity reasons. The research company’s name and the names of the representative consultants were not anonymized because it was not necessary. See Table 1. for an overview of all the interviewees.

Company	Industry	Name	Description of Role	Date and Time	Interview Length
Alpha	Manufacturing	Fabian	Analyzing what potential ideas should be patented.	2022/04/22 14:00	59:98:00

⁵ Note that the epithets “consultants” and “experts” will be used interchangeably throughout the thesis. Nonetheless, both titles refer to Ben and Ferdia.

Alpha	Manufacturing	Nina	Analyzing potential emerging markets.	2022/04/25 18:00	57:49:00
Beta	Packaging	Liam	Analyzing ways of making packaging more efficient and sustainable.	2022/04/26 14:00	55:45:00
Gamma	Manufacturing	Pia	Ensuring good data quality for strategists and business development.	2022/05/10	62:02:00
Ortelius	Consultancy & IT	Ben	Ensuring customer success	2022/04/21 10:00	80:50:00
Ortelius	Consultancy & IT	Ferdia	Ensuring customer success	2022/04/28 11:00	53:50:00

Table 1: Overview of Interviewees (Developed by researchers)

3.3.3. Interview Transcription

All interview participants consented to an audio recording of the interview, and all interviews were transcribed verbatim. The recording of interviews allowed for a more detailed recreation of the session and enabled the researchers to shift all focus towards guiding the respondent and asking probing questions (Bell, Bryman & Harley, 2018). The recording of interviews also allowed the researchers to more easily distinguish what was actually mentioned. The transcription service offered by [Trint](#) was used to transcribe the material. This program performed admirably for the intended purpose. However, it was still decided that the material needed to be reviewed again to revise any possible misinterpretations made by the AI.

As noted by Patel & Davidson (2003), there is always a risk in recording an interview as it can make the interviewees become more aware of how they express themselves so that it sounds correct and logical, which could in turn affect their response. Nevertheless, the researchers still argue that they reduced this problem by clearly stating that the sole purpose of the recording was to aid the transcription process and ensure that no answers were misinterpreted.

3.4. Data Analysis

Eisenhardt (1989) suggests that the analysis of data is one of the most crucial and difficult aspects of a case study. In a similar vein, Creswell & Creswell (2018) stress the importance of doing a proper data analysis as it helps to improve the understanding of the collected data. According to Bell, Bryman & Harley (2018), one of the most common approaches to qualitative data analysis is searching for themes in transcripts or field notes. Therefore, after the data collection, the transcripts were analyzed carefully with a clear coding procedure, following a thematic analysis approach. This choice offered an accessible and theoretically flexible approach to analyzing the data. This was particularly important since meaning was central to this study and employing a thematic analysis approach allowed the researchers to observe and make sense of shared meanings and experiences across the data set (Braun & Clarke, 2006). This involved the researchers engaging in an interpretative relationship with the transcripts.

More specifically, Gioia, Corley & Hamilton's (2013) data analysis method was employed. Here, the scheme starts by identifying first-order concepts, further leading to second-order themes and finally forming aggregated dimensions. This method was judged by the thesis authors to be particularly well suited to the present study because it aided in the development of emerging concepts by systematically elucidating and identifying relations between the transcripts. An alternative approach would have been to begin with a within-case analysis and then move on to a cross-case analysis (Eisenhardt, 1989). However, it was deemed as a less appropriate option because only one of the companies had more than one company representative. Importantly, prior to initiating the thematic coding of data, the process began first with gaining a general understanding of the information gathered.

The researchers thoroughly reviewed the transcript of one interview before proceeding to examine the others, case-by-case. The review of transcripts was done separately by both researchers, whereby notes (e.g., keywords, phrases) of what was interesting or significant about what a certain respondent stated were attached to segments of the transcribed material in Google Docs, across the cases. As suggested by Braun & Clarke (2006), this first stage was solely focused on reading and rereading the transcripts because each reading held the potential to bring new insights to the surface. After becoming acquainted with each transcript, a first-order analysis was initiated whereby these preliminary notes were transformed into clear and precise phrases intended to capture the essence of what has been said in the interview transcripts relevant to answering the research question. These were later cross-checked by both researchers to see if one had identified aspects the other had missed, thus reducing the subjectivity that is otherwise often related to qualitative data analysis (Bell, Bryman & Harley, 2018). Similarities and/or differences across the client companies were later discussed together, which is in line with the comparative design of this study. This transformation of initial notes into first-order concepts ended up generating a large number of initial concepts.

Following completion of the first-order analysis, the coding moved on to the second-order analysis. The second step entailed looking for connections and recurring patterns as well as similarities and differences between the first-order concepts. This process outplayed in an iterative manner as the researchers continued by re-reading the material to see if new concepts and codes emerged and in order to eliminate potential redundancies and overlaps. This eventually helped the researchers reduce the first-order concepts to potential themes that represent a common idea. Finally, the identified second-order themes were refined to a higher level of abstraction, allowing the researchers to consolidate and cluster them into aggregated dimensions.

A conceptual coding scheme that captures and presents the final overarching themes is provided in Figure 1. The three levels of abstraction formed the basis for the Empirics chapter. In the Empirics chapter, the themes are justified by presenting supporting evidence and also (if encountered) potential information that contradicts the general perspective of the theme. By presenting these contrary results, the themes become more realistic and valid (Creswell &

Creswell, 2018). After choosing which quotes to use to illustrate these tensions, the interview transcripts were checked to ensure that the quotes were not misconstrued.

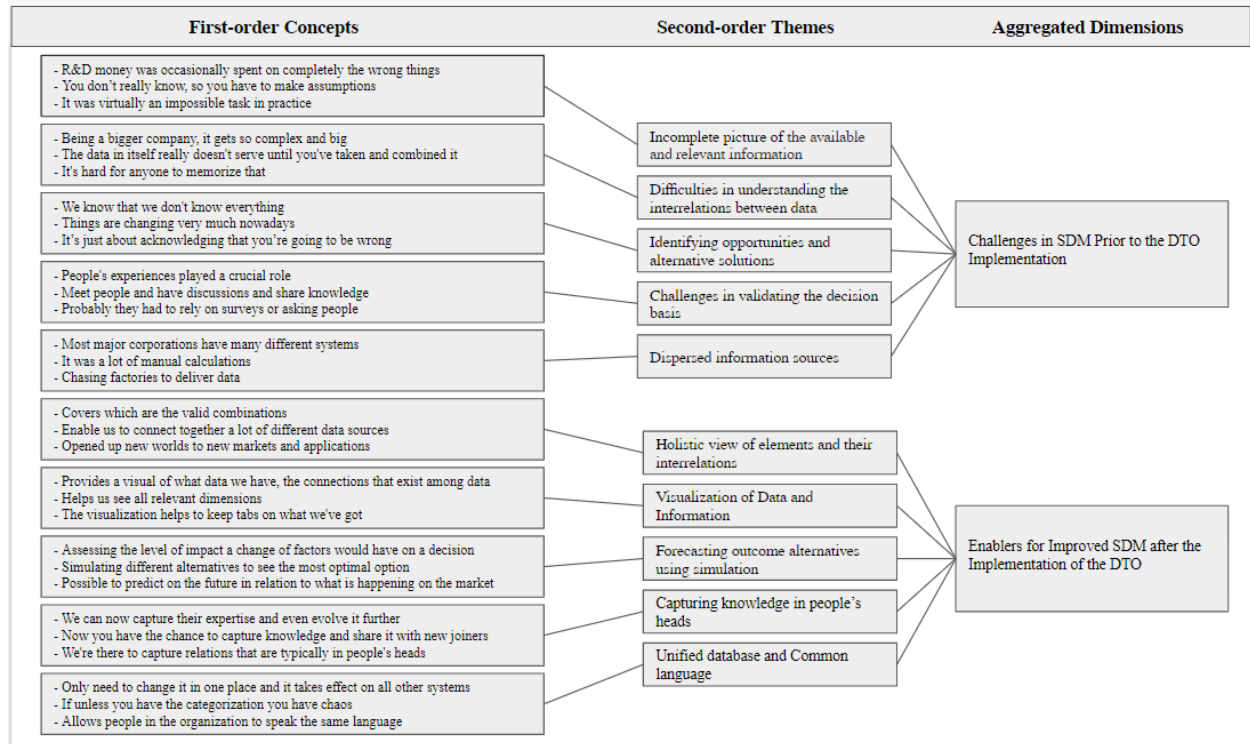


Figure 1: Data Coding Scheme (Developed by researchers)

3.5. Methodological Discussion

3.5.1. Ethical Considerations

Among others, Creswell & Creswell (2018) recognize the significance of ethical considerations, particularly in qualitative research. Similarly, it was important to the researchers that the study be conducted ethically. First, the participants were informed, both in written text before booking the interview and verbally during the interview, regarding the aim and scope of the thesis, as well as their expected contribution. It was also explained how the data would be handled in light of the fact that the conversation would be recorded, emphasizing that all disclosed information would be used solely for the scientific purpose of this study. These measures enabled the potential candidates to make an informed decision about their potential involvement in the study. Second, to protect the interviewees' privacy, their identities, as well as the client companies' names, were

anonymized. Furthermore, anonymity helps to reduce the risk that sensitive information can be traced back to the given company, potentially harming its reputation and image. Third, to avoid causing harm to the interviewees, they were made aware of the fact that they, at any time, could choose to withdraw since participation in the study was completely voluntary. It was further clarified during the interview that they could also pass questions that they perceived as excessively private or inappropriate.

The outlined actions demonstrate that the study complies with the three main ethical principles (*avoidance of harm, informed consent, and privacy*) as explained by Bell, Bryman & Harley (2018). As a result, it can be concluded that this study was carried out ethically.

3.5.2. Trustworthiness

Essential criteria of any research are validity and reliability (Creswell & Creswell, 2018). Validity refers to the accuracy of the findings from the standpoint of the researchers, the respondent or the readers of an account (Creswell & Creswell, 2018). Reliability refers to the repeatability of the conducted operations and findings. Although these two concepts have been applied to the practice of qualitative research, there are those that argue that they are inapplicable or inappropriate in qualitative studies (Bell, Bryman & Harley, 2018). Lincoln & Guba (1985) propose “trustworthiness” as a criterion for assessing the quality of a qualitative study. According to Bell, Bryman & Harley (2018) the concept of trustworthiness can be seen as synonymous with validity and reliability when conducting qualitative research. The trustworthiness aspect consists of four criteria, each of which has a parallel with the previous criteria in quantitative research (Bell, Bryman & Harley, 2018). These are (1) *credibility* which parallels internal validity, (2) *transferability* which parallels external validity, (3) *dependability* which parallels reliability, and (4) *confirmability* which parallels objectivity.

The establishment of the *credibility* of findings entails both ensuring that research is measured as the notion of good practice and the submittance of research findings to the interviewees (Bell, Bryman & Harley, 2018). Accordingly, the thesis was sent to all the interviewees that participated in the study. In addition, by outlining and meticulously documenting the research

process in its entirety, the researchers argue that enough transparency was ensured for the readers to be able to evaluate the generated research results on their own (Bell, Bryman & Harley, 2018). As such, the criteria of credibility can be deemed adequately addressed.

Transferability is concerned with whether the generated data can be generalized beyond the context of this study (Bell, Bryman & Harley, 2018). The researchers can neither confirm nor deny that the study's findings are transferable to a greater extent given the sample size. This is consistent with Conrad & Serlin (2011), who argue that transferability is generally more difficult to achieve due to the smaller sample size of qualitative studies. What is more, the fact that it is a convenience sample makes the generalization aspect all the more difficult (Bell, Bryman & Harley, 2018). However, in an effort to increase the transferability, the reader has been provided with a meticulously written methodology, clearly and transparently outlining the research process as well as the boundaries surrounding this thesis. Moreover, since the findings are based on a multiple-case study, i.e., they are derived from different companies and not from a single case exploration, this suggests that the results are not company- or/and industry-specific. This line of reasoning implies some degree of transferability (Conrad & Serlin 2011; Bell, Bryman & Harley, 2018). As a result, the thesis authors contend that sufficient precautions were taken to ensure a certain level of transferability.

According to Bell, Bryman & Harley (2018) *dependability* refers to the possible reapplication and replicability of the research. Considering the fact that the respondents' meanings only represent one version of reality, the generated results in this study may not be replicable (Conrad & Serlin, 2011). In light of this aspect, the researchers took special care to ensure as much transparency as possible throughout the research process. For instance, a detailed depiction of the methodological process has been provided. Additionally, the peer reviews provided during the mid-seminar and the continuous dialogue with the thesis supervisor further ensured that the correct processes were followed. Worth noting is that since the auditors did not have access to the entire dataset, this constituted another risk that might have affected the dependability. However, deliberately choosing to cross-check all relevant aspects of this study (e.g., the transcripts, interview guides) enabled more auditing, in this case, between the researchers. By doing this, the

possibility of an information cascade and the effect of implicitly biased perceptions were reduced. Together, these measures created an audit trail that both held the researchers accountable while it also made it easier for potential future researchers to replicate the study, thus, increasing this study's level of dependability.

Confirmability concerns the overall objectivity of the researchers (Bell, Bryman & Harley, 2018). Although the researchers did their best to remain open to various perspectives by having reflexivity in mind when deciding during the research process, complete objectivity in a constructivist study is not possible to attain, according to Bell, Bryman & Harley (2018). Nonetheless, the researchers tried to, in various ways, ensure that personal views and expectations did not taint the interpretations and that a full picture of the situation was instead presented. As a result, the researchers would not be locked into a particular path too soon. For instance, by choosing to perform the coding separately before discussing and by always cross-checking each other, particularly during the data analysis process, the impact of the researchers' personal values on the research process was further reduced to some extent at least. By taking these measures into account throughout the research process, in addition to providing a detailed transparent study design, the researchers are confident that the generated results possess a sufficient level of confirmability (Conrad & Serlin, 2011).

4. Empirical Findings

The following chapter will provide an overview of the findings that were gathered from interviews with two experts and four practitioners. The results serve as the basis for the analysis in the next chapter. The case companies will be briefly outlined to provide the reader with a contextual background of the studied cases. To ensure validity, the results from the interviews are partially compared to the answers from the expert interviews. In addition, only first-order concepts mentioned by two or more managers are considered in the findings. The headings reflect the aggregated dimensions, further divided into the second-order themes under which the results for the first-order concept are presented in a cross-case manner (see Figure 1 for a reminder).

4.1. Case Descriptions

Case company Alpha: Manager Fabian, Sweden, and Manager Nina, US

The Swedish company has operated for over a hundred years in the manufacturing industry and is focusing on products and solutions for the heavy industry. The company is operating globally with globally dispersed subsidiaries. Fabian is overlooking the company's patents and focuses on managing innovations that could later be protected. In her role as a business development manager, Nina is responsible for analyzing business opportunities and exploring emerging markets the company can expand in. About the reason for starting the DTO project with Ortelius ten years ago, Fabian mentioned that innovation management was not the initial reason. But it became more and more the focus because they soon realized the potential of the DTO and how it can help the company to decide in which innovation endeavors they should further invest to provide the customers with premium products to ultimately stay competitive in the long term.

Case company Beta: Manager Liam, Sweden

Case company Beta is a Swedish-Swiss company operating globally in the food packaging and processing industry. Liam is a manager in the company's development and technology division. In his role, he manages the specification for packaging materials, including the various base materials. When the company started its cooperation with Ortelius around 15 years ago, Liam

said they were not consciously planning to build a DT. He mentioned that the initial purpose was to support the company in managing product specifications. But over the years, Ortelius' DTO solution has been steadily growing, and today's form can't be compared to when they started. Regarding the DTO's potential to support the company's innovation efforts, he highlighted its capabilities in comparing and testing various kinds of packing material combinations, which is especially useful in reaching the company's sustainability targets for its packages.

Case company Gamma: Manager Pia, Sweden

Case company Gamma is a manufacturing company and 100% owned by a Swedish company group in the retail industry. Pia's role in the company as the data and information process leader is to ensure correct and valuable data and information available to the business and, in part, to support strategies and large projects to become successful. One of the major challenges she mentioned was to synchronize and harmonize the different factories across Europe. Pia stated that one of the main reasons for implementing Ortelius' DTO solution was to tackle that challenge and ensure a consistent data model and good data quality. By doing so, the company sought to improve the product quality and allow cross-factory communication, and ultimately support faster and better-informed decision-making, especially during emergency situations.

4.2. Challenges in SDM Prior to the DTO Implementation

It was clear from all interviewees that prior to the implementation of the DTO, there was a greater tendency to make strategic decisions based on assumptions because they did not have a complete understanding of all facts involved and/or had the ability to comprehend a large amount of raw data available. Throughout the analysis of the transcriptions of the interviews, it also became obvious that the respondent's decision-making relied mostly on their own and other people's experiences as well as dispersed internal and external fact sources (e.g., financial statements, reports, etc.). This led to the overarching challenges that have been identified: (1) Incomplete picture of the available and relevant information, (2) Identifying opportunities and alternative solutions, (3) Challenges validating the decision basis, (4) Difficulties in understanding interrelations of data, (5) Dispersed information sources.

Incomplete picture of the available and relevant information

Fabian explained that prior to the implementation of the DTO, decisions were often based on assumptions as they did not have a complete picture of all available information and that this was the main reason why R&D money was occasionally spent on “completely the wrong things [e.g., patents] because it [the decision] wasn’t fact-based.” He further explained that “qualified guesses” were also made, meaning guesses based on experience. Following a similar line of reasoning, Liam expressed that “the information was not as accurate as now [after the implementation of the DTO] [...] because you know, if you don’t have the full picture, it increases the risk of attacking the wrong things when you want to improve something.” “You don’t really know, so you have to make assumptions and do something that could end up being right or maybe not so right.” He further illuminated this by explaining the difficulty they had with reaching correct estimates by stating that, in theory, they could have “sat down with a pen and paper and gone through a humongous amount of excel sheets and data in other systems and tried to make all these calculations, but it would have taken a tremendous amount of effort and time. So I mean, it was virtually an impossible task.” Nina also disclosed that she used to jump to conclusions a lot quicker before the implementation because she did not have all the facts. Pia did not have much insight into this aspect but stated that her guess would be that there were more decisions based on assumptions ex ante the DTO implementation.

Difficulties in understanding the interrelations between data

Fabian mentioned exemplified the difficulties in understanding the interrelations of data by saying, “If you have a small company with very few patents, it's easier to have that dialog, but as far as being a bigger company, it gets so complex and big, so we didn't have the time to have all the discussions prior to the implementation [of the DTO].” Nina stated that “you're always having to take tons and tons of data, and the data in itself really doesn't serve until you've taken it combined up with other data and then derived insights from it.” Nina further highlighted this challenge by not having the option to visualize data. “You are only able to digest and sort of develop insights from data as you are able to visualize it...it is more like looking at something in 3D versus flat”. She further mentioned, “Spreadsheets upon spreadsheets and folders, and I do

have tons of data. But what is it worth, what is going to really give you that golden nugget, that sweet spot of where you should play?” Ben also acknowledged the difficulties here by stating that “today, companies have, for instance, 18 000 products and 800 different applications within 50 different industries. It's hard for anyone to memorize that”.

Identifying opportunities and alternative solutions

Fabian illustrated the prevailing complexity and uncertainty in identifying opportunities and developing solutions by pointing out that “You need to be humble. I think at least from my team, we know that we don't know everything, and we are open to see that there are other ways to do it because that's kind of fundamental when you work with patterns, you can't be biased saying that this is the best solution as there can be other best solutions we haven't yet discovered”. He continued by pointing to the highly dynamic environment businesses are operating in today by saying that “this is especially important since things are changing very much nowadays”. In a similar vein, Liam said that “You very rarely have all the answers, you know, because then it would be very easy to make decisions. But the world isn't like that. However, the more information you have, the better decisions you're going to make in the long run, and this is certain.” Nina also underlines the importance of this realization by stating that “it's inevitable, it's just about acknowledging that you're going to be wrong.”

Challenges validating the decision basis

Fabian emphasized that people's experiences played a crucial role prior to the implementation of the DTO. He gave an example where they would talk to people “who work in the market who are out and talking to customers” or “meet people who are in the same kind of area of the market to have discussions and share [knowledge]” to gather information. In a similar vein, Nina from the same company mentioned that “a lot of the insights came internally ... from our sales team, they are also our channels and have a lot of information from out there” which are then shared across the organization. Liam stated he does not have full transparency about how it was done previously throughout the company, but he said, “probably they had to rely on surveys or asking people, you know, what will happen if we do this and send out questions to contacts, factories and one way or another to see, you know, what could happen if we change, whatever. So I think

it was a lot more manual process which has been a lot slower, obviously.” And further pointed out the uncertainty that came with it.

Dispersed information sources

Internal and external fact sources were mentioned as equally important. For example, Fabian said that they consulted “marketplaces on what could be the next trend” and further explained that most major corporations have “so many different systems” and information is hence dispersed across the organization. Nina added that internally, the company sought data from their financial reports but also from external sources like government sites. Liam pointed out that prior to having the DTO available, it was “more manual work involved. The information wasn't as accurate as we have it now”. “You know, if you don't have the full picture, the risk is that you attack the wrong thing, when you want to improve something ... it was a lot of manual calculations, and trying to gather data from different sources and in Excel spreadsheets and what have you.” Pia reflected that “there can be a huge amount of data happening on the machines because there are a lot of sensors, there are a lot of points where we can collect the data.” Like Liam, she also mentioned the challenges in gathering data manually and that the information was not available to other factories in the organization, instead “you would have to go to every factory and ask oh, do you produce [this article], how do you want to put it into your database? That's very time-consuming.” Even more, she underpinned the difficulties of communicating the data without a unified data source. “They were also chasing factories to deliver data by email in some structure. They were asking suppliers how much did we buy from you over the last four years?”

4.3. Enablers for Improved SDM After the DTO Implementation

Following the DTO implementation, it was made obvious by all the respondents that, in particular, certain factors aided them in the process of making better fact-based strategic decisions. More specifically, the DTO provided the managers with (1) a holistic view of elements and their interrelations, (2) the possibility to visualize data and information, (3) the ability to generate forecasts for various alternatives through simulation, (4) a way of capturing knowledge

that was previously mostly held in different people's heads, and (5) a unified database/common language.

Holistic view of elements and their interrelations

Liam stated that with the DTO, they were more aware of the facts they have and how they were related. He explained that there, in some cases, exist “several thousands of possible combinations basically. This system [DTO] covers, you know, which are the valid combinations of all these different materials.” Also, he expressed that when “you start drawing connections the surface area keeps getting bigger because you realize that now you can connect this component with this and that, and that enables you to make another connection with something and so it continues. It [the DTO] guides you to where the growth potential is and we haven't been able to do this in this way before”. “The impossible became possible with the system [DTO] Ortelius provided us”, he summarized. Fabian stated that with the help of the DTO, qualified guesses could be “backed up with more data from different areas”. “The DTO that Ortelius provided us can enable us to connect together a lot of different data sources and present it in a way that you can get more facts to base your decisions on because you now have most information in one place under a common reference” He also underlined that since the DTO provides real data, this allows them to now make “true assumptions [...] and thereby reach better decisions”. Nina also explained that by “mixing and matching separate connections, things can get super interesting because you see things that you hadn't thought of before [...] It opened up new worlds to new markets and applications I hadn't thought of before. There is no way in hell my mind could be able to do all of that. So yeah, having the ability to kind of drag and drop was so powerful for me and a bit humbling because it made me check myself first. It [the DTO] basically forces you to hold off assumptions and make sure that you've looked at everything from a bunch of different angles and that you have all of the components in place, and that you're not just jumping to conclusions.

Confirming what the respondents have reported, Ben from Ortelius also explained that having the possibility to see (change and add) potential connections and interrelations among elements is highly valuable as it makes the users aware of things they previously had not realized and which they might be losing money on. “At least it [the DTO] makes them have those discussions right?”

he summarized. Ferdia, also from Ortelius, described that by drawing these connections between data they ensure a reasonable categorization where nothing is too big to be defined. And in turn, the moment you have defined something, different people can then relate to it when exploring new connections without the need to start from scratch to agree on what something is. Ferdia added that managers “can communicate more openly because they can rely on others having this more of a holistic picture.”

Visualization of data and information

Fabian mentioned that with the visualization capability, “it is easier to present the data” and “it's more like your own limits of what data you want”. Further, “by visualizing it, you realize things and question yourself okay, but why do we actually have that [data] in so many different systems? And this is what it [the DTO] helped us with, automating a lot of these processes and providing a visualization of what data we have, the connections that exist among data, and what really might be redundant.” Nina highlighted the value of being able to visualize all relevant angles by explaining that “I can look at the market as a whole and also look at applications and places I wouldn't even think of going versus if it was flat, now we are able to see all relevant dimensions...we couldn't do it in the past.” She further elaborated that “It kind of guides us in the direction of where we should play you know. I think the tool helps you to refine your target and get to that point before you do all that. I used to collect tons and tons and half of it I didn't even use, so it [the DTO] guides you to focus on what [information] you actually need to gather”. Liam mentioned that “the visualization helps us to keep tabs on what we've got and what our weak points are. So what we maybe should focus on next, you know, in this area.” Pia talked about visualizing organizational structure changes by saying, “They're changing relations, putting a new structure, restructure. It takes two days... It is very easy to do it in one place and also see the old structure. So that I would say is a very powerful, powerful thing for a company to have”. She further stated that “It's like a multidimensional model of things which are happening in the world, in business, in industry.” Ferdia explained that “from a visualization perspective, we would like to see out of thousands of objects and this huge network how everything connects and be able to pull out those little bits that I want to work with, that I want to connect things with and connect them back into the bigger picture. So, it [the DTO] allows this kind of small view that is

part of the larger view, which is a very important aspect.” Ben summarized by stating that “the DTO provides the user with a visual representation of an organization’s components and their interrelations” which in turn results in a deeper understanding of reality and what ought to be done.

Forecasting outcome alternatives using simulation

Liam noted that being able to simulate different alternative actions when trying to fathom what might happen has been very valuable. For instance, the DTO has helped to “forecast how much a certain customer is going to buy of this particular product, in the next 12 months”. But the DTO has also helped with “assessing the level of impact a change of factors would have before a decision is taken to see what would happen.” Similarly, Pia explained that being able to simulate different scenarios based on different market predictions was highly valuable. With the help of the DTO, “it was, for example, possible to predict on the future in relation to what was happening on the market [...], say, if the market signaled that the cost of material might go up, then we could simulate what would happen if the cost went up by 20% or 70%. You know, the impact that changes in costs would have on prices of materials and so on.” In line with Liam’s and Pia’s explanations, Nina mentioned that “it [the DTO] allowed us to play around and simulate different alternatives to see which option was the most optimal, for example, do we want to innovate how to develop a spray dryer or acquire a company with spray dryers?”. Similar to what the respondents reported, Ben also explained that with the help of the DTO, companies can “hedge their bets of where the world is going to go and where they should invest in the could-be scenario”. Ben further elaborated that the could-be scenarios give “great flexibility in deciding what to do” because it helps the user with eliciting revelations of current inefficiencies and several alternative outcomes. “But you need to first know your could-be scenarios in order to make those decisions, and that can’t really be done if you haven’t mapped it out”, Ben emphasized. Ferdia explains that the possibility of simulating decisions ultimately results in less uncertainty and more confidence about future outcomes. He mentions that in comparison to other systems, “they don’t really represent what is in your organization, how you look at it? So it’s more that it looks towards the to-be of the future [of your organization] and what things are about.”

Capturing knowledge in people's heads

Nina exemplified this aspect by explaining that “we have brilliant engineers and, you know, they have their masters in chemical engineering and applications and years of experience that we were using. But they left, they retired, you know, and so did the knowledge with them. Well, this is where we can capture it, with the help of the DTO we can capture their expertise and even evolve it further.” She further elaborated that “We have our internal knowledge captured here for new entrants into the company to take a look at and also to ensure that we capture it before someone retires [...] that's fantastic to be able to start with a foundation and not just with a white sheet of paper every time.” Pia also highlighted the aspect of being able to transfer knowledge to new joiners by saying “now you have the chance to capture knowledge and share that with new joiners”. Ben and Ferdia explained in a similar way that “This information is not, you know, something that's easy to automate. It's knowledge in people's heads”. “We're there to capture relations that are typically in people's heads. So the primary biggest challenge is getting the right people from the customer in the room to spend the right amount of time to build up this level of understanding that we need and that they need to own and govern that data going forward.”

Unified database and common language

All respondents mentioned how the data logic that was built in the DTO became the basis for many other tools and systems. Fabian mentioned that “in a good situation, you only need to change it in one place and it takes effect on all other systems as well. So it is sure that you work with more consistent data.” Liam pointed out the importance of having a unified database and said that “You have to have a good underlying data model to understand how these different products and the different things fit together and how they are linked together. But once you've got that ... that's the strength of the system [the DTO] as well.” Nina said that “We use it, you know, for everything from our categorization in finance to our web ... I can't imagine not having it to use”. “It was always sort of the foundation ... since they [Ortelius] started with us, and it just keeps growing”. “So if unless you have that [categorization], you have chaos” and later added “I am in the digital twin all day”. Pia said that “if we as [company name] wouldn't have the DTO, we wouldn't have the same way of structuring the knowledge of the data and wouldn't be able to compare. “Without having the DTO, because they [the different factories] don't talk to

each other, they are competitors to each other” and added “60 people who are purchasing for the whole company and they, without the DTO, they would be blind, they wouldn't be able to talk to the suppliers in the industry as a company because they wouldn't have the data". Ben from Ortelius explained it by saying, “we are capturing the definitions and rules of an organization [...] how you see the world, your digital twin of your organization. And then we're putting the rules and other intricacies on that”. “If you do it [changing the data] in the DTO, you manage it once, and the other systems consume that structure. So that change would just be automatically overwritten in every system that would need to consume that structure.” Ferdia summarized it by saying, “the main thing here is basically the database” and later also touched on the point that this unified database allows people in the organization to speak the same language. Companies typically frame their problem by saying “our core departments or people, they don't speak to each other. They cannot speak to each other because they would speak marketing, they speak production, and they basically cannot really transport their message. So using the same terminology and speaking the same language allows different teams to compare their results and they can contribute to each other's findings more easily.

5. Discussion

This chapter expands on the previous chapter's analysis by comparing and positioning the empirical findings within the existing body of literature identified in the literature review. The challenges are discussed based on their potential source of biases and the capabilities of the DTO that were found to hold the potential to mitigate them. Figure 2 provides an overview of the discussed findings. This chapter then extends the interconnected findings, elevating a discussion beyond the biases that were found to be mitigated, thus elucidating insights the analysis may propose about the potential of a DTO introducing or/and reinforcing new ones.

5.1. The Interplay Between SDM Challenges, Cognitive Biases, and DTO Enablers

Incomplete picture - Biases - Holistic view

The challenge for managers of only having an incomplete picture of the available and relevant information induced a potential source for the availability bias and the confirmation bias. The DTO can mitigate these biases by providing a holistic view of various elements and their interrelations.

The incomplete picture of all relevant information, their interlinkages, and the sheer amount of unstructured information was described as overwhelming using various terms. In line with previous literature, the complexity level perceived by the interviewed managers is a result of their imperfect knowledge about the data that was important to deciding about their companies' resource allocation in their innovation efforts (Mintzberg, Raisinghani & Théorêt, 1976; Molloy & Schwenk, 1995). Accordingly, in an attempt to try to fill in the gaps of missing information when making strategic decisions, the managers explained that they relied on drawing different assumptions and did the best they could with what they had at hand. The results show that, on one hand, jumping to conclusions with incomplete information was perceived to be advantageous as it allowed for swift decision making. On the other hand, it often resulted in inefficient allocation of resources. The interviewed managers explained that the assumptions that were not fact-based were often based on experience, which according to Schwenk (1988) in turn formed the basis for the frames of reference (i.e., how they categorized information) through which they

later reached a decision. More specifically, the decisions that were based on assumptions might have been overly biased toward the managers' experiences prior to the DTO implementation. This is referred to as "business as usual" by Hammond, Keeney & Raiffa (2015), and "confirmation bias" by Mahoney (1977), because a decision-maker is choosing among a repertoire of tried alternatives or redefining a problem to one that they have previously experienced, where a tried solution exists. Another bias, which is related to confirmation bias, that might have come into play and affected the managers' decision-making is the "availability bias". According to literature, managers may have believed that whatever category-consistent information they discovered during their information acquisition process reflected the truth, and it was thus disproportionately weighed more when considering alternatives. Furthermore, the literature suggests that the managers could have assumed that the missing information was consistent with the way the issue was categorized. (Dutton & Jackson, 1987; Barr, Stimpert & Huff, 1992; Tan & Platts, 2003)

A prerequisite for optimal decision-making (e.g., opting for the best resource allocation) requires taking into account a multitude of perspectives (Molloy & Schwenk, 1995) by collecting and processing all relevant information (Daft & Weick, 1984; Choo, 1996; Citroen, 2011). The empirical findings show that the DTO provided the respective decision-makers with a more consolidated picture of all relevant data and potential variable linkages. This, in turn, lowered and/or eliminated the perceived uncertainty and helped the managers to make better-informed decisions that steered their innovation efforts more in line with the ever-changing environment (Frishammar, 2003). They had to rely less on forming assumptions and were more able to underpin their assumptions with facts. Among others, the managers exemplified that this fuller picture helped point to where they should play and also helped illuminate what was missing and what the weak points were.

Relation diffuseness - Biases - Visualization

The difficulties in understanding the interrelations between data induced the potential for the framing bias and the confirmation bias. The DTO can mitigate these biases by providing a visualization of their company's business operations displaying all elements' connections and interrelationships.

The managers acknowledged the difficulty in being able to digest the amount of data available and understand how the data is linked in order to derive insights from it. This is in line with the literature suggesting humans are cognitively limited and have a hard time understanding complex systems (March & Simon, 1958; Acciarini, Brunetta & Boccardelli, 2020; Becker & Pentland, 2022). This lack of understanding of how elements are related suggests that the managers might have been blinded to potentially more connections between data and subsequent insights when making decisions, causing them to fall prey to the framing bias (Tversky & Kahneman, 1981). More specifically, this gap in knowledge caused them to frame their problematizations and solutions based on those limited linkages that they could see. Another related bias that could have reinforced this behavior is the confirmation bias, as the managers potentially sought the comfort of the known (Mahoney, 1977). This means, as the managers focused their attention on what they could see, potentially leaving out more angles and perspectives, they continued making decisions based on this familiarity, further confirming this limited and, at times, distorted frame of reference.

The DTO provided the managers with an extensive insight into the network of a company's business operations, visualizing the relationships and interrelationships of all elements of their respective organizations. This was especially useful for the managers as the visual representation of data and information and their interrelations eased the information processing and allowed them to more easily develop insights from this greater knowledge and understanding. Furthermore, the visual view of the network brought unknown connections and interrelationships to the forefront of the managers' awareness, allowing them to recognize their gaps in knowledge and more easily break distorted mental habits. This is in line with previous research showing that visualizing organizational processes, relationships, and key metrics can bring in key insights for decision-makers (e.g., Tan & Platts, 2003; Yan, Hong & Warren, 2021).

Outcome ambiguity - Biases - Forecasting

The challenge in identifying opportunities and alternative solutions induced the potential for the framing bias and the confirmation bias. The DTO can mitigate these biases by providing a dedicated simulation capability.

The managers relied on the expert's experience when trying to identify new opportunities or pointing out challenges, which was especially highlighted by Nina. But how an opportunity or challenge is characterized can be influenced by the perception of the individual, by that person's mental model, holding the potential for the framing bias (Tversky & Kahneman, 1981). Moreover, confronted with complexity and the need to take action, the literature suggests that humans tend to seek the comfort of the known, whether appropriate or not (Tan & Platts, 2003). This means, in turn, that the managers might have been prone to the confirmation bias as they sought after alternative solutions that confirmed previously tried alternatives (Mahoney, 1977).

The empirical results show that the DTO enabled the exploration of scenarios and alternatives by offering dedicated forecasting/simulation capabilities. Barr, Stimpert & Huff (1992) demonstrated that an organization's ability to successfully adapt to external changes correlates with managers' mental models for developing new beliefs about cause and effect relationships. Accordingly, by allowing the managers to forecast and experiment with different hypotheses, they were exposed to more possibilities of the unknown. These insights, in turn, helped stretch their frames, aided their mental model, and thereby supported them in developing sounder and more accurate solutions. As explained by literature, the ability to predict more accurately what the outcome(s) of a decision might be, lowers the level of uncertainty and, thereby, the urge to employ heuristics (Duncan, 1972).

Validation difficulties - Biases - Knowledge capture

The challenge for managers to not being able to fully validate their decision basis induces a potential source for the halo effect, overconfidence, and confirmation bias. The DTO can mitigate these biases by capturing the knowledge that was previously only stored in peoples' heads and making it accessible to every employee in the same form at the same time.

Seeking the opinion of co-workers, customers, and partners when making a decision was highly valued because the managers relied on their experience. Employees whose expertise was valued in a certain area, such as in a specific market, were approached to provide input and share their knowledge, from which the managers sought more information to make a better-informed decision. The expertise itself is seen as an important complementary part to factual knowledge also in the literature (see, e.g., Bennett, 1998). There is a potential risk that if others attribute that person to be an expert in a certain area, others are less likely to question their opinion, but also in other areas. Such situations make individuals prone to fall prey to the halo effect. (Kahneman, 2013) Furthermore, the potential risk exists that the conclusion of the experts might be biased by overconfidence, by overestimating their knowledge in the face of a high level of uncertainty (Bradley, 1981). Finally, the managers themselves might have subconsciously only reached out to people supporting their view, falling prey to the confirmation bias by only seeking information that confirmed their opinion (Mahoney, 1977), essentially inferring they were framed by those opinions beforehand (Tversky & Kahneman, 1981).

All managers emphasized the strength of the DTO to transform the knowledge that was previously only in peoples' heads into data and make it accessible to everyone else. The consultants from Ortelius highlighted this task as the central aspect when building the DTO. The potential of the DTO to capture explicit as well as tacit knowledge within one system was also recognized in the literature (Meierhofer et al., 2021; West et al., 2021). Now that the informal knowledge is no longer dependent on being communicated, it is also no longer dependent on the communicator's mental model. As mentioned, it has been shown that the mental model is largely responsible for what an individual perceives to be of relevance in responding to a certain situation (Kiesler & Sproull, 1982). This uncertainty factor can be avoided with the DTO. Every individual has access to the same knowledge at the same time. Further, it does not get lost when one employee leaves the company, as pointed out by, among others, Nina.

Dispersed information sources - Biases - Unified database

The challenge of information being dispersed across different sources induces a potential source for the availability bias and the anchoring bias. The DTO can mitigate these biases by providing a unified database and allowing all employees to speak the same language.

Gathering the right information was described as a manual task and required effort as the internal and external information sources were dispersed across different systems in the organization. Information was less likely to be accurate and resulted in a higher level of uncertainty when making decisions, and made it more difficult to set a focus on the companies' innovation efforts. Collecting information would often involve communication work by calling or emailing people to provide them. Acciarini, Brunetta & Boccardelli (2020) already pointed out that biases are especially likely to occur when analyzing information, e.g., when searching for environmental trends. Without a fast and easy way to gather information, the managers might be more likely to rely on their or other individuals' experiences, respectively on their tacit knowledge (Bennett, 1998). In a situation where time is pressuring, they might rely on the information they are able to find first in one of the multiple systems, holding the potential subconsciously to anchor themselves to the first information found (Tversky & Kahneman, 1974). Further, without quick access to the information needed, the managers might rely on what is coming to their minds first. Both scenarios indicate a potential source for the availability bias (Tversky & Kahneman, 1973).

The DTO constitutes the underlying logic and becomes the basis for many other systems. It ensures that data is categorized and structured in the same way across the whole organization, ultimately allowing people to speak a common language, ultimately decreasing the level of uncertainty. The DTO holds the potential to address the mentioned issue that organizations often lack an overview model to indicate which data is relevant (Gartner, 2021). In addition, having a unified database eased the acquisition of knowledge, whereby the managers now can more easily find relevant information to back up their assumptions and validate their thinking. They are also able to draw from a broader as well as more diverse set of possibilities and insights stemming from a unified database. This has been shown to be a critical aspect of any decision-support process (West et al., 2021).

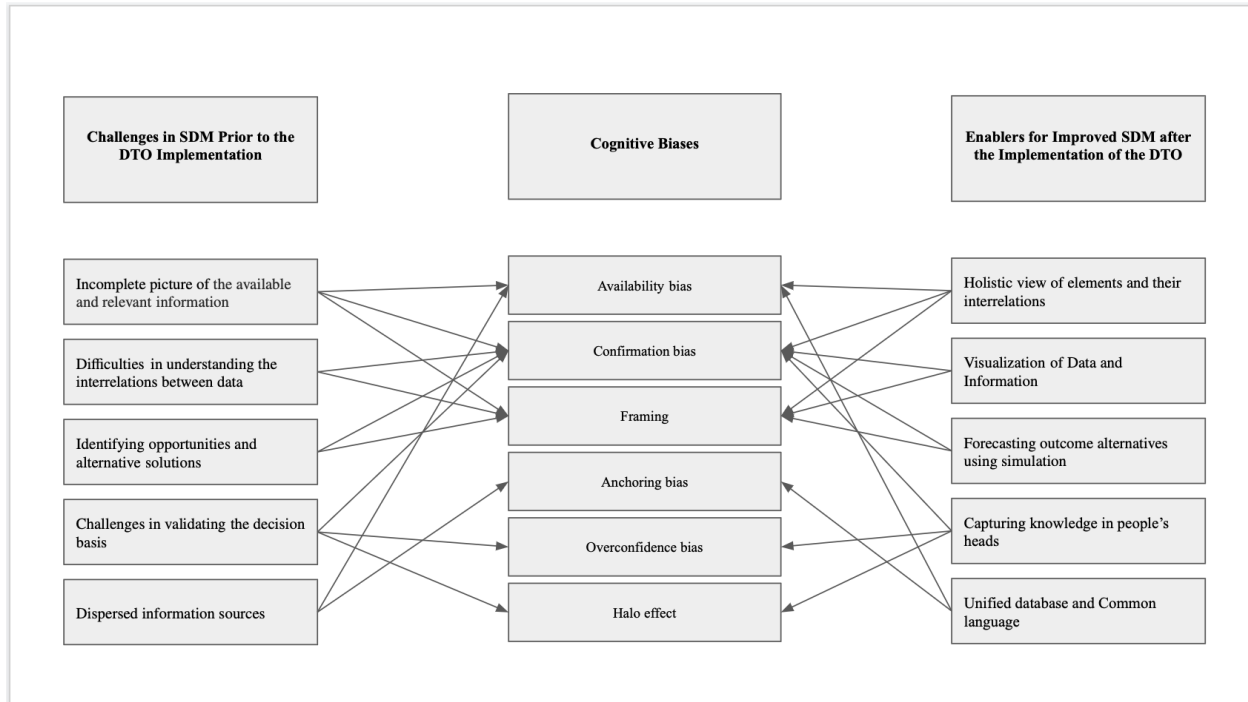


Figure 2: Overview of the interplay between challenges, cognitive biases, and DTO enablers (Developed by researchers)

5.2. Further Discussion

The analysis demonstrates that the interviewed managers faced different challenges in their SDM that, in several ways, induced the occurrence of biases prior to the DTO implementation. More specifically, indications of the availability bias, confirmation bias, framing bias, anchoring bias, overconfidence bias, and the halo effect were found. No clear indications were found on the existence or mitigation of the herding behavior (Lee & Lee, 2012) and reactance (Murray & Häubl, 2011).

The results of this thesis are consistent with previous studies suggesting that IS holds vast potential in supporting SDM (Molloy & Schwenk, 1995; Browne & Parsons 2012; Godefroid et al., 2021) and more specifically a DT technology (see Caporuscio et al., 2020; Parmar, Leiponen & Thomas, 2020; Yan, Hong & Warren, 2021; West et al., 2021; Gyunam, Comuzzi & Van der Aalst, 2022). However, these results expand on the implications of Yan, Hong & Warren (2021), who insinuated that the utilization of a DT technology can help managers shift from subjective

thinking to more objective evidence-based decision-making, yet did not demonstrate how this plays out in practice.

As previously noted in the literature review, studies have suggested that an IS equally holds the potential to reinforce existing biases and/or introduce new ones (Turpin & Plooy, 2004). The practitioners and experts have explained that the DTO unfolds its full potential the more areas of the company are included, which means continuously expanding the scope of the DTO. This might indicate that over time, the managers could subconsciously become affected by the sunk cost fallacy (Arkes & Blumer, 1985), where they would continue the investments, irrespective if the benefits outweigh the costs. However, all respondents indicated that, so far, the cost savings resulting from having the DTO at hand were much higher than the initial investment. Ben and Ferdia from Ortelius pointed out that the value of the DTO increases over time while the investments required decrease. It can therefore be said that, at least in the analyzed cases, the risk of the sunk-cost bias is rather low, if existent at all. Furthermore, as mentioned by Lurie & Mason (2007), the way information is presented can be distorting. Therefore, the possibility exists that the DTO not only mitigates bias such as anchoring or framing but reinforces it, depending on the design of the system. Other instances where biases have distorted the individual's decision-making process after starting to use the DTO to support the companies' innovation management have not been part of the analysis and can therefore neither be denied nor confirmed.

During the interviews with the practitioners, it became apparent that they all spoke very enthusiastically about having the DTO support their company's innovation endeavors. Critical aspects have only been mentioned in terms of the costs and the required change management to establish the concept and the adoption of it among the workforce. However, it cannot be ruled out that the managers subconsciously justify the DTO in an overly positive way (Clark, Robert & Hampton, 2016). This suggests that there is a potential risk that the proven potential of a DTO can make the managers overestimate their abilities in comprehensively evaluating all relevant variables needed to make accurate and objective strategic decisions. Furthermore, the interviewed managers described how winning key stakeholders supporting the establishment of

the DTO concept in the company can be challenging. Worth mentioning is that the concept of the DTO is still in its infancy, often competing against major legacy IT systems, although that is a misconception, as the purpose is rather to support these systems. Therefore, a political motivation behind the statements given in the interviews might exist.

Finally, it is worth noting that the empirical findings also indicated that simply being open and humble about the prevailing complexity and acknowledging that having a complete picture of a situation is almost impossible already caused awareness of imperfect SDM. Even the awareness of these circumstances enabled decision-makers to understand their mental traps. This is in line with Hammond, Keeney & Raiffa (1998), who state that the best defense against biases is always awareness. Having said that, this means that it cannot be claimed that merely the distinct DTO capabilities as outlined in the previous chapter mitigate the occurrence of cognitive biases. However, the potential of the DTO in mitigating the occurrence of biases has been shown. All participants have emphasized how the DTO has enabled them to identify innovation opportunities. There is a clear indication that the DTO has improved communication and knowledge sharing.

6. Concluding Remarks

The aim of this thesis was to answer the following RQ:

“How can a digital twin technology help mitigate managers’ cognitive biases when making strategic decisions to steer their company’s innovation management?”

The inquiry of this thesis followed the call by academia for more research in the field of cognitive biases in an IS context, especially to advance the current findings on the implications in practice. It further accounted for the crucial role of innovation management and shed light on the interplay between DT technology and SDM. Based on the empirical findings and the subsequent analysis and discussion, it can be said that a DT technology, holding the same or similar attributes as the DT used by the practitioners, can help mitigate manager’s cognitive biases when making decisions to steer their company’s innovation management by (1) providing a holistic overview of elements and their interrelations, (2) presenting data and information in a visualized way, (3) forecasting solutions and outcomes using simulation, (4) capturing knowledge that was previously only in people’s heads, and (5) providing a common database that allows speaking the same language. It has been argued how these capabilities of a DT serve as enablers to a better-informed SDM and how they can help counteract biases that have been identified to occur prior to having a DT available. As an outcome, the studied managers have been found to be able to make strategic decisions with a lower risk of the decisions being distorted by the negative effects of cognitive biases. Thus, easing the process of achieving organization-environment alignment and ensuring long-term competitiveness of their organization.

6.1. Theoretical and Practical Implications

Theoretical implications

The applied research methodology showed different strengths and weaknesses of the inquiry in the field of interest. On one hand, it became clear that research about the potential of DT technology in mitigating biases has to consider and examine the situation in a company prior to

the implementation. By identifying the priorly existing challenges, it was possible to draw conclusions on the risk of cognitive biases occurring and subsequently identify the enablers of a DT that target them. It has been shown that biases can be caused by different challenges, thus, research focusing on specific biases have to account for that. On the other hand, even though various patterns in the statements of the interviewees have been identified, it can never be ruled out that when researching the usage of technology in an organizational context, statements given might be driven by personal perception, experience, or any political motivation. These factors have to be taken into account when studying cognitive biases in an IS context. In addition, the diversity of the DT technologies that exist has been described in the literature review. Hence, the differences in the characteristics of DT technology have to be considered.

Practical implications

This research contributed to a better understanding of which challenges in SDM existed compared to a situation after the implementation of a DT. It is hoped that this will cause general awareness about the pitfalls that exist for managers involved in SDM in their company's innovation management. Furthermore, companies having a DT technology in use can take the findings and apply them to further develop their DT technology, focusing on which enablers and how they support SDM in consideration of cognitive biases. Companies that have not yet identified a solution that supports them in dealing with the prevailing complexity in their innovation strategy might consider the findings in their search. Lastly, DT technology vendors might take the findings of this thesis into consideration in the design, development, and implementation of a DT system to address the identified challenges and potential biases more targeted.

6.2. Theoretical and Practical Limitations and Future Research

Theoretical limitations

Theory suggests that biases can have two types of sources: a) cognition and b) motivation (Larrick, 2004; Shaikh, 2022). However, Browne & Parsons (2012) mentioned that all biases are cognitive biases and are not mutually exclusive. A greater distinction between these two types is not drawn in this thesis. Furthermore, since decision-making is a rather broad topic, this study is

focusing on *SDM in innovation management*. The notion of SDM is understood as a technique to “cope with the complexity of processes found at a strategic level” (Mintzberg, Raisinghani & Théorêt, 1976, p. 246) in delimitation to other SDM techniques, such as strategic planning or cost-benefit analysis (Mintzberg, Raisinghani & Théorêt, 1976). Limitations also had to be made in terms of the level of analysis at which the decision-making was studied (individual, group, or organization). Future researchers might therefore focus on group or organization decision-making.

Limitations have also been drawn by examining the impact of cognitive biases in SDM. Other factors, such as interpersonal dynamics, demographic factors, and diversity in experience (Acciarini, Brunetta & Boccardelli, 2020) have not been considered and might be of interest for future research studying DTs in practice. In addition, only a selection of biases from the literature have been considered and was the focus of the analysis. Future researchers can extend the list of cognitive biases to provide additional results.

Empirical limitations

The studied phenomenon is only explored through a qualitative inquiry by conducting in-depth interviews with two representatives from a DT software provider and four of its clients (i.e., practitioners). No additional data from either the software company or its clients were used to support the results. Observation as a means of inquiry would have certainly allowed more insights and a deeper understanding of SDM behavior but would have also been “extremely demanding of research resources because strategic decision processes typically span periods of years; often forced to study the process after completion. Therefore, the researcher is obliged to rely heavily on interviewing.” (Mintzberg, Raisinghani & Théorêt, 1976, p. 248)

Furthermore, this study only focuses on SDM within the context of certain industries, specifically: manufacturing and packaging. Only managers involved in their company’s innovation management have been approached. Delimitations also needed to be made regarding the number of respondents involved in the study in order to still have time to analyze the empirical material. Hence, the results of this study can be limited to their subjective view.

Future research with more research capacities can build on the results of this thesis and further extend the research scope to other industries or business functions to provide more insights. The results can serve as a reference point for comparing the results. Considering the theoretical and empirical limitations, the conclusions drawn from this study should be applied with caution to other contexts outside of this setting. However, to increase the transferability of the findings, a thorough and carefully written description of the study design is provided. The researchers are looking forward to more insights into the interesting field of cognitive biases, DT technology, and SDM in innovation management.

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Appendix

Appendix I.

Interview Guide: Expert Interviews

The following list of themes guided our interviews with room for variation and adaptation depending on the interviewees answers during the interviews

To mention before the interview

- Voice will be recorded
- Personal name can be anonymized if wished
- The interview will only be used for the purpose of our thesis

Questions

- I. What makes your product special, compared to “regular” DTs out there?
What differentiates a DTO from a regular DT (e.g., features, component level etc.)?
- II. What are the typical problems clients seek to solve with your DTO?
E.g., identify problems, improvement areas and innovation efforts
- III. What are typical use cases or scenarios for using the DTO to acquire information?
E.g., for supporting strategic decision-making in innovation management
- IV. Relevant strategic information in innovation management: How does the DTO capture internal and external information?
E.g., What sources are used?
- V. How do you advise your clients to use the system?
E.g., How are they trained?

- VI. How many key users are typically involved?
Identify Group thinking biases implications

Appendix II.

Interview Guide: Client Interviews

The following list of themes guided our interviews with room for variation and adaptation depending on the interviewees answers during the interviews

To mention before the interview

- Voice will be recorded
- Personal and company names can be anonymized if wished
- The interview will only be used for the purpose of our thesis
- Ortelius doesn't have any influence on the questions or the evaluation of the data
- Restate purpose of thesis (topic)

Questions

Theme 1: Reasons for DTO implementation

- Opening question: Can you give a bit of a background on your company's innovation efforts and your role in it?

What were the (fundamental) reasons for implementing the DTO?

E.g., What issue did you/ your company try to solve by implementing the DTO?

Theme 2: Decision-making ex-ante DTO implementation

- How did you (personally) make decisions in the past? More specifically, describe how you decided on strategic actions that affected the innovation management in your company before the DTO implementation?

- What kind of information did you use to validate your decisions?

Kind of information in the sense of hard information = in reports, excel sheets etc. can (mostly) be quantified, soft information = images, visions, ideas, gossip, or hearsay

- Where (from which sources) did you obtain this information? What specific sources (tools like information systems or others) did you use?

Internal and external sources

- How did you argue for the chosen alternative?

Assuming there were several

Theme 3: Decision-making ex-post DTO implementation

- How did your “decision-making process” change since the implementation of the DTO?
- How do you make decisions with the support of the DTO?

To describe the (strategic) decision-making (process) (in innovation management)

- Which kind of information was retrieved from the DTO?
- How was the information identified?
- How did you argue for the chosen alternative?

Theme 4: Resume of usage

- Now ex post, how did it actually play out; did it perform as initially intended? What worked and what did not? Justify.

Appendix III.

Introductory Statement

The information provided in the introductory statement was restated verbally during the interview as well. Find the entire form attached below.

Master's Thesis Request for Participation

Dear potential interviewee,

We, Qendresa and Dennis, are two students from Lund School of Economics and Management and are currently writing our master's thesis in International Strategic Management.

Short Thesis Abstract:

Contemporary research literature has identified different major trends currently challenging innovation management in manufacturing firms, among them openness, servitization and digitalisation. Digital twin technology was identified to be a supportive tool to respond to these trends. With our thesis, we aim to explore how strategic decision-making within innovation management is impacted when implementing a DTO solution.

Key Facts:

- All statements and identities will be (if preferred) anonymized
- Targeted interview candidates: Holders of a managerial role within a manufacturing (or manufacturing-related company) who are directly involved in the company's innovation efforts alignment
- The company has implemented Ortelius' digital twin technology and the interviewees are using the tool to support their decision-making
- Planned weeks for the interviews: Calendar week 16-17
- Interview length: 1-1:30 hour long session
- Interview recording: Voice will be recorded and only be used for this thesis
- Interview language: English (preferred) or Swedish
- Where: Zoom/Teams or your preferred video conference platform

To be able to conduct our thesis, we are dependent on your voluntary participation. In case you want to help us, could you please provide us with two-three time slots that would work for you

within calendar week 16-17? If you have any questions or concerns before the interview, we are of course happy to discuss them upfront.

For you to have a face to our names:

Qendresa's LinkedIn profile

Dennis' LinkedIn profile

Thank you very much in advance for supporting us in our thesis process!

Best Regards,

Qendresa Balaj & Dennis Weber