

Framing Potential Influences of Digital Transformation of Manufacturing SMEs

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Abstract

The transformation towards digitization, also known as Industry 4.0, is a significant trend in the manufacturing sector. It promises substantial benefits such as competitive advantage, enhanced customization, high-quality products, reduced costs, and shorter lead times. However, for Small and Medium-sized Enterprises (SMEs), this transition is more challenging compared to larger corporations. SMEs face barriers, including limited resources, inadequate technical infrastructure, and organizational resistance to change. The study concludes that a more holistic approach is essential for SMEs to successfully transition to a digitalized environment. By understanding the interrelations and external and internal dependencies within their business models, SMEs can make informed decisions and develop effective digital strategies. By adopting a Systems Thinking approach, SMEs can gain a holistic understanding of these challenges and develop strategic solutions to address them. It allows SMEs to view their business models comprehensively, considering all elements and their interconnections. This approach helps in identifying interdependencies, revealing previously unnoticed relationships, and designing effective digital strategies. The value addition of this approach lies in its ability to provide a clear roadmap for digital transformation, addressing both internal and external challenges faced by SMEs.

Keywords

Digital Transformation, Systems Thinking, Interdependency, Manufacturing SME, Strategy

1. Introduction

Digital transformation is considered as an ongoing process in the digitalization of a company, leveraging digital and data-driven innovations to improve existing

processes and operations, alter business model elements, or reinvent the entire business model. Due to their resources, larger companies are often better positioned for digital transformation than SMEs. The latter face several challenges that put them at risk as larger players venture into traditionally SME-dominated markets through a more efficient digital transformation (cf. Gierlich et al., 2019; Barann et al., 2019).

The primary objective of the study is to offer a holistic Systems Thinking concept to analyse the different aspects—options, challenges and barriers—faced by manufacturing SMEs in digital transformation in order to propose strategies to overcome these challenges. The questions addressed in this approach include:

- What is the current situation of manufacturing SMEs towards digitalization?
- What are the important aspects to digitalization for SMEs?
- What elements should be focused on to address these aspects in a systems thinking model?
- How do these elements influence each other within the system?

2. Literature Review

The barriers that SMEs face in their transition to digitalization, can be categorized into techno-economical, organizational, human resource, and customer-related barriers.

1) Techno-economical Barriers: SMEs often lack the financial resources and technical expertise required to adopt advanced technologies like IoT, data analytics, and cloud computing (Paschou et al., 2018; Mittal et al., 2018). The high costs associated with implementing these technologies pose a significant challenge for SMEs. Additionally, the rapid pace of technological advancements requires continuous investment in upgrading infrastructure and skills, which can be dissuasive for resource-constrained SMEs. Furthermore, the integration of new technologies with existing systems can be complex and time-consuming, leading to operational disruptions.

2) Organizational Barriers: SMEs often reveal a lack of strategic integration of digital technologies. Organizational resistance to change and inadequate innovation management also pose significant challenges (Kane et al., 2015; Lerch & Gotsch, 2015). SMEs may have entrenched processes and hierarchical structures that hinder the adoption of new technologies. Moreover, the lack of a clear digital strategy and vision can lead to fragmented efforts and suboptimal outcomes (Hu & Kee, 2022). Effective change management practices are essential to address these organizational challenges and ensure a smooth transition to digitalization.

3) Human Resource Barriers: SMEs struggle with a shortage of skilled employees who can handle digital technologies. Training programs are often inadequate, leading to a gap in digital skills (Lerch & Gotsch, 2015; Peillon & Dubruc, 2019). Cultural resistance to change is another significant barrier, as employees may be reluctant to adopt new ways of working (Rehman et al., 2021).

4) Customer-Related Barriers: Unclear customer needs and concerns about

data privacy and security hinder the adoption of digital technologies by SMEs (Klein et al., 2018; Peillon & Dubruc, 2019).

Understanding these barriers, embracing digital trends, mitigating the technical and organisational gaps and recruiting skilled labour, even during times of shortage, are crucial for developing effective strategies to facilitate digital transformation in SMEs and therewith to maintain their market position. (Abel-Koch et al., 2019). Meanwhile, digital technologies also offer SMEs significant opportunities to develop new business models expand their customer base and strengthen customer loyalty. For SMEs to compete effectively with larger companies, they need to utilise these technologies to streamline operations and increase productivity, often resulting in significant time and cost savings through integrated IT systems, e-invoicing and cloud applications. All those aspects have to be viewed simultaneously and systematically and resulting interdependencies have to be considered.

3. Methodology

Systems Thinking can contribute to determining important aspects of a digital transformation process, including their correlation, as it is a framework that focuses on interrelationships and patterns, integrating principles from physical, social sciences, engineering, and management (Van Laar et al., 2017). Systems Modelling, a primary tool of Systems Thinking, depicts a mental model (cf. Jones et al., 2011) that provides a structural view of real-world systems acting as a proxy for real scenarios to understand possible consequences and test counter actions before implementation (Zürn et al., 2022).

It is beneficially used for understanding business dynamics (Arnold & Wade, 2015), visualizing relationships, communicate mental models, and making goal-oriented decisions (Ballin, 2012; Müller et al., 2023). In this respect, it is an appropriate methodology for a holistic approach to understanding and managing the complexities of digital transformation. This approach helps in identifying interdependencies, revealing previously unnoticed relationships, and designing effective digital strategies (Rajagopal et al., 2024).

4. Results

4.1. Clusters and Key Elements

From a systematic literature analysis the authors could derive a comprehensive overview of 18 key elements that influence significantly the success (or failure) of a manufacturing SME's digital transformation process. The 18 key elements could be categorised into six main clusters: Data & Connectivity, Customer Satisfaction, Product Value, Operations & Processes, Transformation Management, and Organizational Agility.

Data & Connectivity

Data Security

Data security is a critical enabler of digital transformation. Ensuring robust

data security measures can enhance customer satisfaction by providing a secure and reliable digital experience. It also supports operational processes by protecting connected technologies and machines from cyber-attacks (Waslo et al., 2017). However, poor management of data security can negate these benefits, leading to potential vulnerabilities and threats. Investments in data security cannot be scaled down, and slow progress in data security activities can leave the organization vulnerable to evolving threats (Aslan et al., 2023).

Data Analytics

Data analytics plays a pivotal role in enhancing customer satisfaction by offering advanced search options, personalized recommendations, and dynamic pricing. It also improves operational efficiency by providing insights that drive business decisions and streamline processes (Le & Liaw, 2017). However, data analytics also raises significant data security concerns and privacy concerns related to real-time behavioural advertising further complicate the use of data analytics (Aiolfi et al., 2021).

Data Integration

Effective data integration is essential for leveraging the benefits of data analytics. It ensures that data collected from various sources is stored on a common platform, facilitating consistent and updated inputs across the organization. This integration supports quick decision-making, enhances operational efficiency, and reduces communication gaps. However, data integration not only poses challenges related to data security but also creates the risk of data silos. Companies must carefully choose the best approach for data integration to avoid these pitfalls (Patel, 2019).

Customer Satisfaction

Customer Interaction

Digital customer interactions significantly enhance customer satisfaction and product value. Companies that are market-oriented and attentive to customer needs can develop superior solutions that meet those needs effectively (Jyoti & Sharma, 2012). However, focusing solely on digital interactions can be counter-productive. Studies show that a combination of digital and human interactions is more valuable for the total customer experience (Weber & Chatzopoulos, 2019).

Customer Experience

A positive digital customer experience enhances customer satisfaction and brand image, contributing to operational efficiency and business performance. However, a single bad digital experience can lead to customer loss. Companies should prioritize technologies that provide speed, convenience, and friendly service (Chaturvedi & Verma, 2022).

Distribution Channels

Digital distribution channels offer significant benefits by integrating customer intelligence tools that enhance customer loyalty and operational efficiency. However, they also increase perceived risks related to product quality and data security, which can negatively influence customer behaviour (Venier, 2022; Frasquet et al., 2015).

Product Value

Individualized Products & Services

Mass customization as a way to more individualized companies to deliver value efficiently, fostering long-term customer relationships. However, as mass customization, it complicates manufacturing processes, increases inventory costs, and challenges supply chain agility (Stojanova et al., 2012). Achieving true individualized products and services demands robust data analytics to predict customer preferences accurately and the integration of all Industry 4.0 technologies (Wang et al., 2017).

Smart Products & Services

Smart products, encompassing a range of IoT devices and smart home technologies, significantly enhance customer satisfaction by offering continuous monitoring and updates. These capabilities allow for real-time adjustments and personalized user experiences, leading to higher levels of user engagement and satisfaction. As smart home devices can learn user preferences over time, leading to more intuitive interactions and improved comfort and convenience they also introduce significant data security risks. Many smart products are often designed with limited attention to robust privacy controls, leaving them vulnerable to unauthorized access and data breaches (Muheidat et al., 2020).

Quality of Products & Services

The quality of a product and the level it can demonstrate compared to competitor products significantly influences customer satisfaction and loyalty (Cahaya et al., 2023). This factor also paves way for recommendations to other buyers to purchase that product, which in turn affects profitability and performance in the organisation's operations and processes. Conversely, inferior products and services lead to a loss of market share, declining sales and higher marketing costs, which affects the company's profitability.

Operations & Processes

Flexible Operations

The degree of flexibility of the manufacturing systems depends upon the degree of flexibility of the workers and machines, where different variants of the product or new product models can be manufactured on the same machine. Flexibility in operations enhances competitiveness and customer satisfaction by allowing quick adaptation to changing market conditions. As a result, the flexible operations enable SMEs to have an efficient system of receiving feedback from customers, align their operations and products according to the customer needs by short processes in decision making, especially within flat structures of an SME organisation (Matejun, 2014). However, implementing flexible operations requires significant investment in technology, involves extensive planning, detail in design and schedule as well as high skilled employees, which may be challenging for SMEs (Kaur et al., 2017).

Digital Supply Network

A digital supply network (DSN) improves operational efficiency and product

value by enhancing the ‘upstream’ activities such as reduction in the operating costs, improvement in the quality of the product and gives a wider and clear visibility of the supply networks. However, it poses challenges in transformation management and data security, as companies may be reluctant to share data due to confidentiality issues and potential cyber threats (Laaper et al., 2018).

Integrated IT Processes

Integrated, harmonized IT processes within manufacturing companies have positive influences on the production & process and make the organisation more agile, flexible and efficient by supporting transparency, efficiency, and long-term planning. However, the interconnected nature of integrated IT processes often comes with software dependencies and creates a virtual ecosystem susceptible to security breaches (Kure et al., 2018).

Transformation Management

Change Management

Effective change management positively influences transformation management and organizational agility, improving performance and competitiveness. However, it comes along with a lot of risks and can be highly challenging when much of its inputs or variables show alterations at the same time, such as the processes, the tools but above all the responsibilities and motivational aspects. Those change management necessities are often not fully included in digital transformation projects. (Bellantuono et al., 2021).

Digital Technology Management

Digital Technology Management imparts technology knowledge to SMEs, aligning it with their business plans, explaining benefits, and framing action plans for smooth integration. The suitability, effectiveness, costs and measured risks are compared and the expertise of employees is assessed. This approach enables SMEs to pursue a broader strategy and develop tools for making informed decisions about the suitability and effectiveness of technologies. (Afolayan & De la Harpe, 2020) Challenges mainly arise from not evaluating technologies before adoption, causing SMEs to miss opportunities for competitive advantage (Nguyen et al., 2015). Moreover, indecision and poor decision making hinder the ability of SMEs to assess the suitability and benefits of the technology before adoption (Afolayan & De la Harpe, 2020).

Digital Strategy

A well-defined digital strategy provides clarity and direction, facilitating effective communication with stakeholders and guiding the digital transformation process. A clear and consistent digital strategy gives an idea to the organization to take small steps in digitalization and how the adaptation of new aspects could be synchronized with existing operations. The absence of a digital strategy can have a drastic effect on all areas of the organization (Cosa, 2024).

Organisational Agility

Shared Leadership

Shared leadership facilitates the fast decision-making process and it reflects

the current scenario on the ground or on the shop floor, fostering agility across the organization (Calnan & Rozen, 2019). In such a system, the reviews, feedbacks and suggestions from the entire system are taken into consideration thus increasing the probability of higher productivity and worker's satisfaction (Mayer et al., 2023). Encouragement of managerial competencies at lower levels, training to take responsibilities and an open communication culture increase the degree of flexibility in the organisation. However, the absence of a strategic, hierarchical decision-making procedure can create power play (Motloun & Lew, 2023), prolong the process even in critical situations and affect accuracy.

Work-Life Balance

A balanced work-life dynamic is beneficial for both employees and organizations. It enhances employee well-being, organizational loyalty, reducing turnover and hiring costs and by that indirectly increasing the productivity (De Sivatte et al., 2015). However, remote working, an aspect of flexible work-life balance, poses data security risks (Curran, 2020) and challenges the flexibility of the workforce, especially in manufacturing SMEs.

Flexible Workforce

A flexible workforce that can quickly fill gaps in shortage of skilled staff improves operational efficiency and agility. The success of using a flexible workforce depends largely on the company's culture with respect to trust and a good knowledge management (Vogel et al., 2021). The absence of a flexible workforce can lead to operational disruptions and unmet customer demands, impacting revenue and market share. For SMEs that do in general not have one-to-one proxies even for critical jobs, this is more important than for larger companies.

4.2. Systems Thinking Model

A Systems Thinking Models is used as a medium through which a mental model of the 18 key elements is created, which is able to give a structural view of the complex real-world system of digital transformation. The purpose of the model is to behave as a proxy for the real scenario, so that the possible consequences or impacts can be better understood, and possible counter actions can be tried and tested before the implementation.

Influence Matrix

As already discussed above, the 18 elements are interrelated to varying degrees. Based on the existing literature and qualitative interviews with experts, a preliminary matrix is developed to illustrate the influences of these individual elements on the six predefined clusters. This methodological approach was chosen to reduce complexity and facilitate a manageable and understandable analysis, allowing a focused examination of the influences of the elements within the cluster framework (Table 1).

Inpulse Chains

The derived influence matrix segregates elements based on their dynamic behaviour, providing insights into the system's complexity. For highlighting areas

Table 1. Influence matrix of the 18 elements on the 6 clusters.

		Results					
		Data & Connectivity	Customer Satisfaction	Product Value	Operations & Processes	Transformation Management	Organisational Agility
Actions							
Data & Connectivity	Data Security		+-		++	-	-
	Data Analytics	-	+-	++	++		
	Data Integration	-			++		++
Customer Satisfaction	Customer Interaction		+-	++			
	Customer Experience		+-	++			
	Distribution Channels	-	+-		++		
Product Value	Individualized Products & Services		++	+	-		
	Smart Products & Services	-	+-		++		
	Quality of Products & Services		+-	+-	+-		
Operations & Processes	Flexible Operations		++		+-		
	(Digital) Supply Network	-	+	+	++	-	
	Integrated IT Processes	-			++		++
Transformation Management	Change Management					+-	++
	Digital Technology Management				++	++	+
	(Digital) Strategy		+-	+-	+-		
Organisational Agility	Shared Leadership				+-		++
	Work-Life Balance	-			+-		+
	Flexible Workforce				++		++

+: reinforcing relationship; ++ strong reinforcing relationship; -: reversing relationship; +/-: relationship could be reinforcing or reversing, depending on the specific element within the cluster.

to focus on for effective digital transformation and guiding decision-making the double loop learning modelling process of [Sterman \(2002\)](#) was followed using a story-telling methodology on impuls chains as proposed and utilized by [Ballin \(2012\)](#), [Martinetti et al. \(2017\)](#), [Zürn et al. \(2022\)](#) and [Rajagopal et al. \(2024\)](#) amongst others.

For the model, a large series of such impulse chains were described to validate the proposed interconnections of the elements. Those impulses deemed most influential were introduced into a goal oriented Systems Thinking model in a seven step procedure as described by [Zürn et al. \(2022\)](#), creating an interdependency network of all elements. [Figure 1](#) shows the resulting systems thinking model.

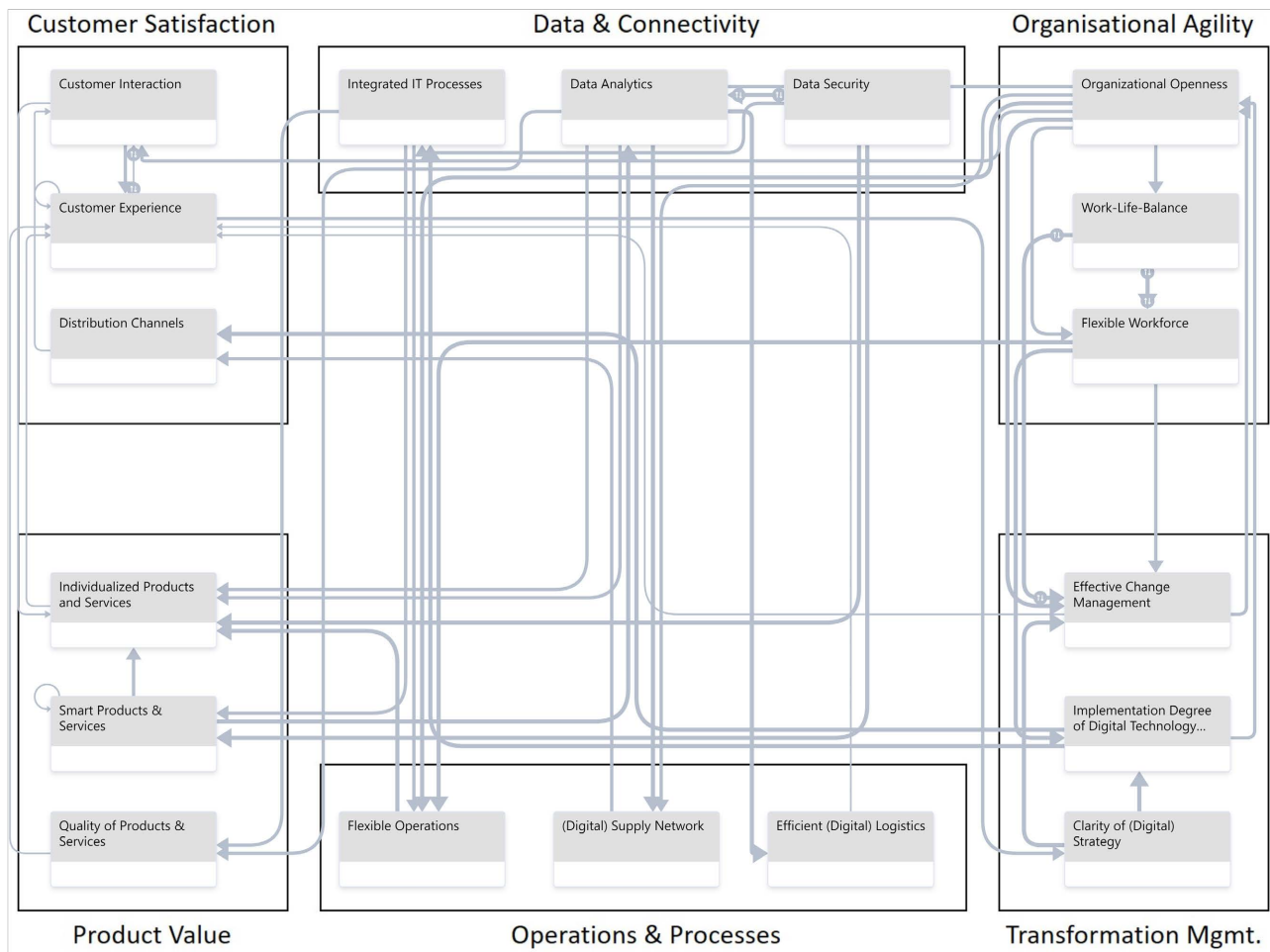


Figure 1. Systems Thinking Model with impulse chains of the 18 elements.

Two impulse chains within the proposed system should work as examples explaining the way the story-telling methodology was used for all relevant relations:

- Clarity of Digital Strategy → Customer Experience (**Figure 2**)

A clear digital strategy ensures that digital initiatives aligned with the company's goals are implemented, enhancing the integrated IT processes in order to enable flexible operations that are necessary to create individualized products and fostering the product quality. Both work towards a better customer experience and as consequence higher customer satisfaction. The need for a coherent digital strategy to drive successful digital transformation becomes visible.

- Work-life Balance → Customer Satisfaction (**Figure 3**)

If employees have a better work-life balance the change management can be more effective to establish an organizational openness. This makes it easier to create a digital supply network that provides new distribution channels with higher customer interaction and enhanced experience, contributing to higher customer satisfaction. This chain illustrates the importance of investing in employee well-being to improve overall business performance.

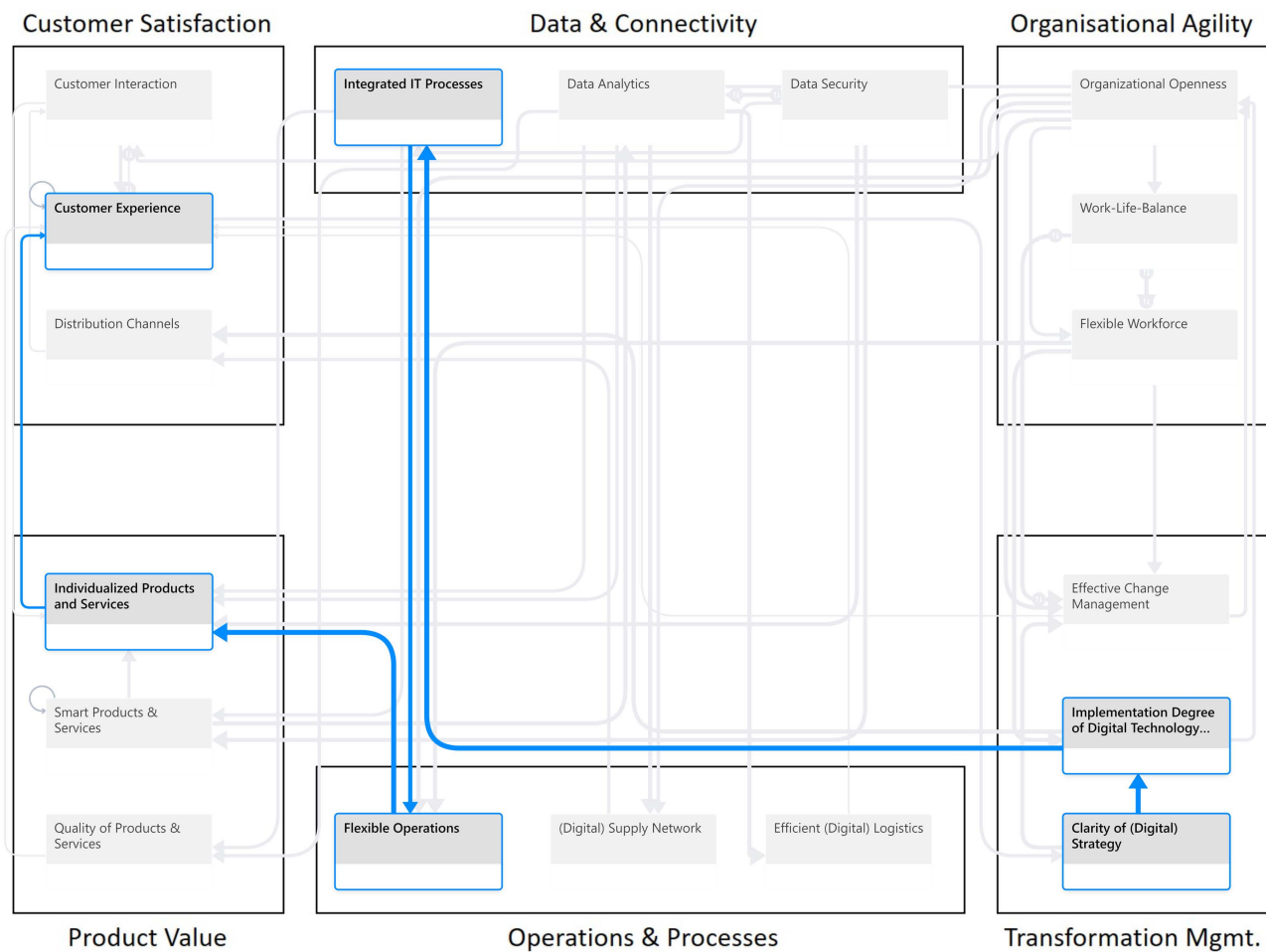


Figure 2. Impuls Chain: Clarity of Digital Strategy → Customer Experience.

5. Conclusion

The presented study provides a comprehensive understanding of the digital transformation landscape for SMEs. The study identifies the critical technical, organizational, human resource, and customer-related challenges that steer the digital transformation process. Systems Thinking offers a holistic approach to understanding and managing the complexities of digital transformation. The proposed model, consisting of eighteen elements, provides a comprehensive framework for SMEs to navigate their digital transformation journey, leveraging interdependencies and addressing potential influences. The insights gained from this research will help SMEs develop effective strategies to navigate the complexities of digitalization and achieve sustainable growth. The report also emphasizes the importance of a phased approach to digital transformation, highlighting the need for incremental changes that align with the organizational capabilities and market dynamics.

6. Implications and future work

The results of this study on systems thinking modelling for SMEs' digital

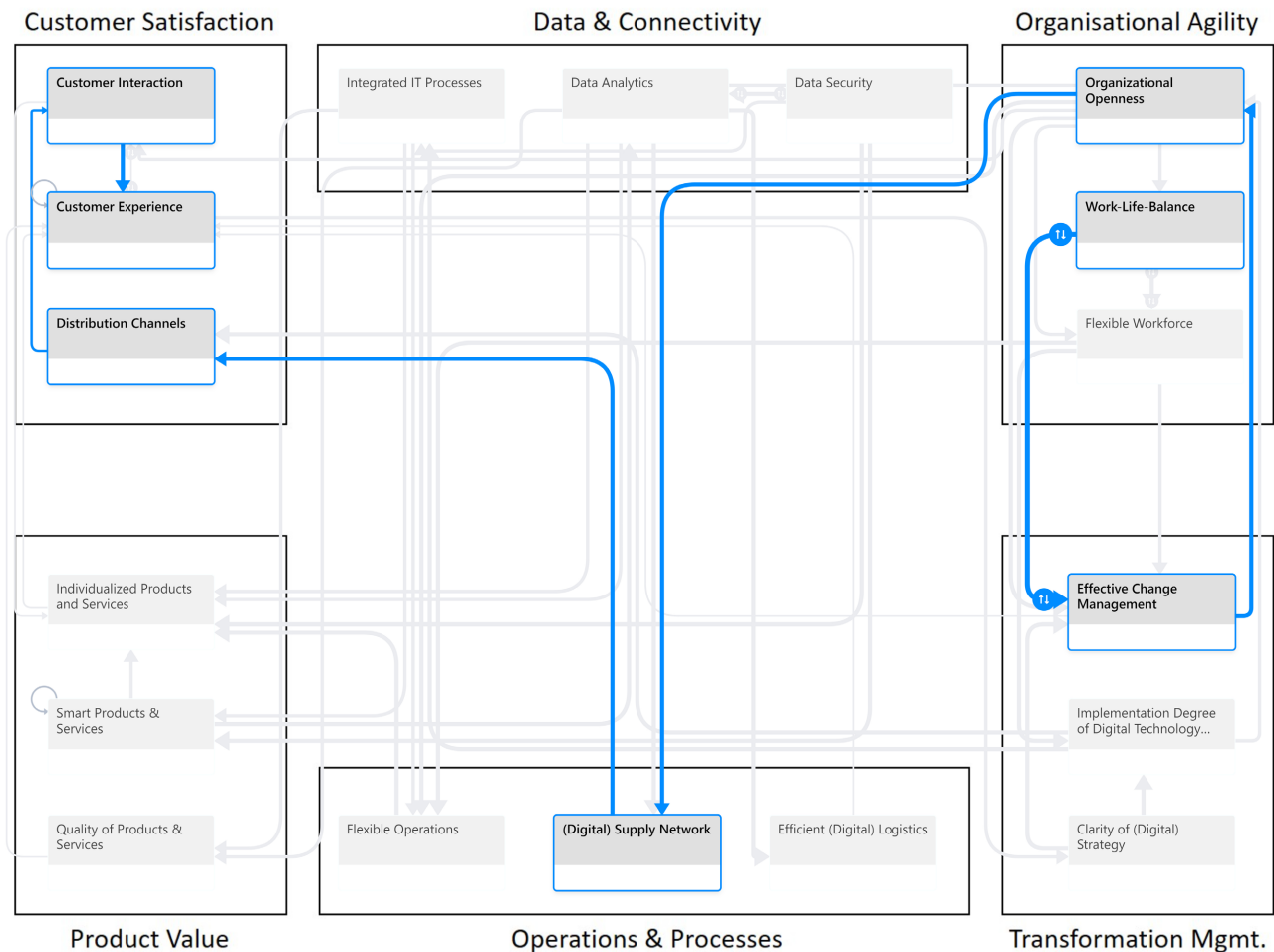


Figure 3. Impuls Chain: Work-life Balance → Customer Satisfaction.

transformation reveal several implications for both current practices and future research. These implications span strategic, operational, and methodological dimensions by offering a comprehensive perspective on leveraging systems thinking to foster successful digital transformation.

By employing systems thinking, SMEs can better understand the interdependencies among actions, leading to more informed and effective strategic decisions. This holistic perspective ensures that digital transformation initiatives are not viewed in isolation but as part of an interconnected system, promoting more sustainable and resilient growth strategies. However, it is necessary that the modelling is adapted to the specific industry or business as the presented results just focus on manufacturing SMEs.

The presented study is qualitative in its nature and future research should build on the proposed model by developing quantitative simulations using a systems dynamics approach to test various digital transformation strategies. This can provide SMEs with even more valuable predictive insights, enabling them to visualize the potential outcomes of different strategic choices and identify optimal paths for digital transformation. In this respect, future research could also

explore the integration of data analytics and machine learning with systems dynamics models to further refine predictions and strategic recommendations. This integration would allow SMEs to enhance their ability to navigate the complexities of digital transformation with greater accuracy and confidence.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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