KEY ASPECTS OF DIGITALISATION IN STABILIZING SUPPLY CHAINS IN THE CASE OF UNEXPECTED DISRUPTIVE EVENTS

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Abstract

Entrepreneurial activity is subject to constant change. Today's world is characterised by optimisation, globalisation and digitalisation. In case of an unexpected disruptive event in this era of coordinated globally distributed supply chains, supply gaps, bottlenecks and other supply chain disturbances occur worldwide. Currently, the SARS-CoV-2 pandemic affects supply chain activities significantly. Coupled with current trends by new technologies, the research question is: How can tools of digitalisation be used to react and counteract quickly against disruptive supply chain events? To answer the question, we develop a conceptual model built upon the three pillars of supply chain, disruptive events, and digitisation tools based on expert interviews and a broad literature review. The model is validated by an inductively created utility analysis, which tests all technologies for their applicability and suitability. Our findings indicate that data analytics and digital automation solutions represent the greatest counter-effects.

Key words: digitalisation, supply chain disturbance, SARS-CoV-2, digitalisation tools, SCOR

1. INTRODUCTION

Today, many companies operate their supply, production and distribution networks on a global level. These global supply chains are organised in a highly efficient manner and take advantage of a so-called flat world (Freeman 2005). The other side of the coin is an increased vulnerability of global supply chain structures and processes to disruptions such as disasters, strikes or other unexpected or unpredictable external disturbances (Skjoett-Larsen et al. 2015).

The financial crisis in 2008 showed that liquidity bottlenecks of single companies in a chain can lead to production downtimes and consequently to huge financial damage for all actors in the chain. Currently, the SARS-CoV-2 pandemic affects the global supply chains massively. As Kantar (2020) reports that the economic consequences of the pandemic go far beyond all expectations due to the closing of borders or other restrictions thus leading delivery bottlenecks, delays, demand fluctuations and liquidity problems. Consequently the pandemic proofs the notions of Skjoett-Larsen et al. (2015) who state that the higher the level of globalisation the higher the exposure to such risks.

Parallel to these developments, the global economy is shifting towards digitalisation so that firms are more and more built on digital business models or use digital tools, which assist internal as well as external interface-less data integration (Hoberg et al. 2019). As such, digitalisation is considered as a generic problem solver (McKinsey 2017).

The purpose of this paper is to examine the capability of digital tools to help to respond and counteract to the SARS-CoV-2 pandemic quickly as well as to assess the preventive effect of these tools in order to avoid negative effects of a pandemic situation. We are particularly interested to see the value of digital tools when it comes to re-stabilise supply chains that are negatively affected by unexpected disturbances.

In order to achieve our goal we develop first a conceptual model of global supply chain. This includes the setting of the global supply chain (2.1.) and the identification of an adequate reference model for modelling a supply chain (2.2). This is followed by the development of a suitable supply chain performance system and relevant key performance indicators (2.3.) as well as the presentation of supply chain relevant digital tools (2.4). Next, we present the notions of supply chain disturbances and show how the SARS-CoV-2 has affected so far global supply chains (2.5). Finally we examine, based on a multi-criteria analysis (3.) the usability of the digital tools to respond to the pandemic outbreak in preventive and reactive manner (4.) and are able to see that digital automation as well as data & analytics have the greatest power to do so. The paper ends with a conclusion and an outlook for future research.

2. THEORETICAL FRAME OF REFERENCE

2.1. Global supply chain network

A global supply chain network integrates logistics and production networks from the raw material stage to the ultimate customer and includes supplier networks, the integrated enterprise as well as distribution networks (Bowersox et al. 2019). Today, supply chains are globally diversified and the involved companies are vertically integrated and simultaneously cooperate on a horizontal level.

The existence of such complex systems is due to increased competition, global customer markets as well as cost pressure. Taking the automotive industry as one example, we also observe increased outsourcing of activities that so-called original equipment manufacturers (OEM) do not consider to be their core competence (Baumgarten & Wolff 1999). This leads to upstream supplier specialisation, which includes systems specialists, components or module suppliers (Warth 2012). Furthermore, companies safeguard their supply networks by cooperating closely with module suppliers or even partly own their suppliers that are located all over the world (Hegmann 2014). And to keep costs at a low level, this industry relies on system integrators between tier-1 suppliers and the OEM, who consolidates and distributes all orders and deliveries at lower costs and allows supplier flexibility. In order to manage such systems, manufacturers apply complex IT-systems that manage the relevant flows and relationships (Bortal 2016).

Looking at the stage of raw material, we see raw material suppliers, who deliver their products downstream to many different supply chains with different structures and conditions (Küster-Simic et al. 2017). And turning to global retailing companies, we see global supplier structures with suppliers spread all over the world combined with local specialties on the downstream parts. These supply chains require a huge degree of transparency along the supply chain and some retailers establish end-to-end supply chains (Döpgen 2018, Li 2007).

Consequently there is a need for a smart design of such global structures that are also heavily impacted by external conditions, which endanger the seamless and smooth flow of goods between raw material stage and ultimate customers.

2.2. Model components

2.2.1. Reference models for designing supply chains

Modelling supply chain structures is a multifaceted task for which particular approaches have been developed such as Collaborative Planning Forecasting & Replenishment (CPFR) (see VICS 1998). the Supply Chain Operation Reference Model (SCOR) (SCC 2012), the Value Reference Model (VRM) (Di Domenico et al. 2007) or the Design Chain Operations Reference (DCOR) (Wu et al. 2007).

CPFR is mainly used in the fast-moving consumer goods industry and can be seen as a kind of Sales & Operations Planning approach (Kotzab & Teller 2003) whereas SCOR includes the supply chain perspective and contains upstream as well as downstream levels (SCC 2012). SCOR is used to describe supply chains and supply chain processes of different companies along a global value chain and can be adapted flexibly (Poppe 2016).

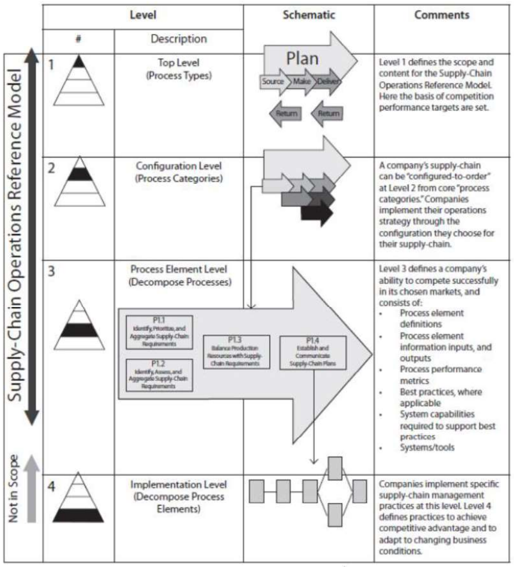
VRM though is adequate to describe internal business processes and distinguishes between three different levels for top-down structuring business areas, processes and activities (Brown 2009) as it differs between product lifecycle management, supply chain management and customer relationship management (Di Domenico et al. 2007).

DCOR is a further development of SCOR and focuses on the structuring of the design processes within companies (Wu et al. 2007). This is mainly due for those markets with a short response time in case of changes of customer demand and if customers have high expectations towards product flexibility. If the model includes the supplier stage, it turns into the Collaborative Design Chain Operations Reference Model (CDCO) that wants to implement the interactions between buyers and their suppliers.

Overall, we selected for our purposes the SCOR approach, as its major advantages are the general applicability, the width by combining internal and external supply chains as well as the profundity in terms of considered levels, which allows a single case observation on a process base (see figure 1).

The SCOR model also includes key performance indicators for all levels that allow a performance-based control of all activities. In case of examining the consequences of a supply chain disturbance such as the SARS-CoV-2 pandemic for a supply chain, the SCOR allows a projection of these on the individual firm level activities as well as on the level of a complete supply chain.

Figure 1. Overview to the SCOR model



Source: (SCC 2012)

2.2.2. Key performance indicators for SCM

When quantifying the successful implementation of supply chain strategies or structures, it is necessary to identify the performance of a supply chain with financial as well as non-financial measures (see Beamon 1999, Gunesekaran et al. 2004 and Sinha/Kotzab 2011). The measurement of the supply chain performance is based on key performance indicators that concentrate on the cross-functional performance of internal processes as well as between suppliers and customers (Fugate et al. 2010).

This includes multiple dimensions, which refer to the strategic, tactical as well as operational level of SCM (Morash 2001. Neely 2003) and between internal as well as external supply chains (Poluha 2010). In case of the SCOR model, this leads to more than 200 different key performance indicators (SCC 2012) out of which only some are useful to identify how technology can help to deal with supply chain disturbances (see Table 1).

2.2.3 Digital tools and digital transformation

Digitalisation refers to a technical-organisational change, which aims at a complete automation of the industrial sector (Matuschek & Kleemann 2018). When it comes to the integration of digital devices, the term 'Industry 4.0' is used as a synonym for digitalisation (BMWi 2020b). According to Obermaier (2019), the degree of digitalisation and integration includes the value chain processes as well as the final products.

The existence of Internet technology and cyber-physical systems are prerequisites for digitalisation. The combination of both is known as the Internet of Things (IoT) (Obermaier 2019). In Table 2, we show some digitalisation tools that are relevant for supply chain digitalisation (see Hoberg et al. 2019).

Table 1. Selected performance indicators

exteranl	Reliability	Perfect Order Fulfilment	Perfect Order Fulfilment % of Orders Delivered in Full Delivery Performance to Customer Commit Date Documentation Accuracy Perfect Condition
	Responsiveness	Order Fulfilment Cycle Time	Order Fulfilment Cycle Time Source Cycle Time Make Cycle Time Delivery Cycle Time
	Agility	Upside SC Flexibility	Upside Supply Chain Flexibility Upside Source Flexibility Upside Make Flexibility Upside Deliver Flexibility Upside Source Return Flexibility Upside Deliver Return Flexibility
		Upside SC Adaptability	Upside Source Adaptability Upside Make Adaptability Upside Deliver Adaptability Upside Source Return Adaptability Upside Deliver Return Adaptability
		Downside SC Adaptability	Downside Supply Adaptability Downside Source Adaptability Downside Make Adaptability Downside Deliver Adaptability

internal	Cost	SCM Costs	Total Supply Chain Management Cost Cost to Plan Cost to Source Cost to Make Cost to Deliver Cost to Return Mitigation Cost
		Cost of Goods Sold	Cost of Goods Sold Cost to Make
	Assets	Cash-to-Cash-Cycle	Cash-to-Cash Cycle Time Days Sales Outstanding Inventory Days of Supply Days of Payable Outstanding
		Return on SC Fixed Assets	Supply Chain Management Cost Cost of Goods Sold Supply Chain Fixed Assets
		Return on Working Capital	Supply Chain Management Cost

Table 2. SCM-adequate digital tools

Digital technology cluster	**Characterisation**	**Examples**
Robotics in intra-logistics systems	Automation of internal logistics processes, especially handling/picking and warehousing	Robotic fulfilment systems, automated picking systems
Autonomous transport means	Transport means that are carrying goods without human steering and control	Platooning, drones, autonomous trucks
Virtual reality and augmented reality	Users receive additional data and information via specific devices	Head-up displays, smart glasses, digital twinning, pick-by-vision
Internet of things	Internet-driven integration of specific devices	Sensors, smart devices
Supply Chain Analytics	Real-time decision support and making by using various data sources/data warehouses	Machine Learning, predictive analytics, data visualisation, business intelligence
Process automation	Automation of processes by the use of robots or digital agents as well as fully automated software	No-touch order processing, blockchain, robotic process automation (RPA)
Platforms	Central data nodes and areas that can be accessed in a decentralised manner	Cloud-based cooperation and communication, crowdsourcing

Source: Hoberg et al. (2019)

For the purpose of our study, we condensed these clusters into four areas that are outlined in Table 3.

Table 3. Selected digitalisation tools for further analysis

Digital tools cluster	Characterisation
Digitalisation	Includes digital process flows document administration, communication, IoT, sensor technology and smart devices
Digital automation	Includes process automation by digital agents, RPA, block chain and other IT-driven technology/devices
Mechanical automation	All mechanical robots, automated transport means, drones, etc.
Data & Analytics	All technology that prepares as well as analyses data, forecasts and supports decision making as well as transparency such as AI, cloud platforms, data-driven business models

2.3. Supply chain disruptions causing supply chain instability

A supply chain disturbance or disruption is an event that negatively impacts the stability of a supply chain (Barroso et al. 2011; Wagner and Bode 2006) and it characterizes the incidence of a supply chain risk (Biedermann 2018). Depending on the degree of the impact. Wohl (2017) distinguishes between (lower impact) disturbances and (higher impact) disasters.

Overall, the proper execution of supply chain processes is threatened by disturbances, which leads to negative consequences of the supply chain performance in terms of ripple effects such as significant delays, lack of inventories or too high levels of inventories (Ivanov and Das 2020).

Examples of major supply chain disturbances in the near past were the sea earthquake in Tohoku (Japan) in March 2011, which affected negatively the automotive industry on a global level due to delivery stops out of this particular region (Hallegatte 2015. Lee 2018). Because of the climate change, cocoa production in Ghana has decreased by nearly 20 % in 2015, which led to massive price increases of this particular raw material (Strom 2015, Heneghan 2016).

Political developments, such as the introduction of punitive customs on the import of foreign products, can also negatively affect supply chains as the Trump administration has proven in the recent past (Pankow 2019. Brown 2018).

Depending on the type of disturbance, firms are able to cope with these by implementing preventive as well as counter measures (Reibnitz 2013) depending whether these measures are taken before or during the disturbance.

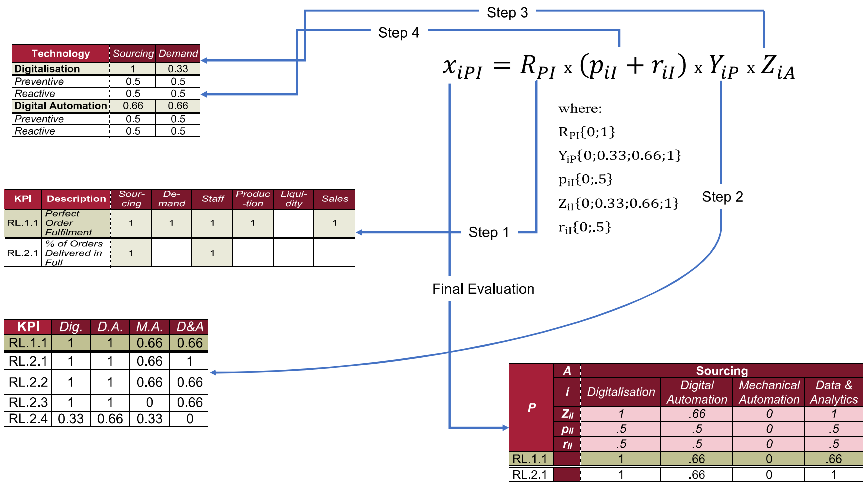
Most recently, the SARS-CoV-2 pandemic has proven the limits of global supply chains as many regions and countries were quickly isolated, borders were closed and quarantines were imposed (Miller 2020). By June 2020, German decision makers identified the following areas to be massively affected by the pandemic (Kantar 202. BMWi 2020a): Decrease of customer demand by more than 50 %; bottlenecks in liquidity in more than 80 % of the cases; temporary closing of operating units or complete sites; logistical challenges when distributing own products; difficulties when sourcing advance services or work-in-progress products; going out of business and staff shortages due to illness, quarantine or child care at around one third of the examined companies.

Based on these results, we grouped the areas that are affected by the pandemic into sourcing, demand, staff, production, liquidity and sales and linked them with the previously defined list of performance indicators (see Table 1) as well as with the digital tools, which we present in the subsequent section (see Tables 2 and 3).

3. METHOD

The overall goal of our research is to examine whether supply chain areas are directly affected by the SARS-CoV-2-pandemic and if a digital tool is able to quickly respond to the situation and to counteract measured by a performance indicator model. In order to solve our problem, we performed a multi-criteria analysis in form of a utility analysis (scoring method) in following steps as outlined in Figure 2: Step 1) Evaluation of the impact of disturbances on selected SCOR performance indicators (R_{PI}; Appendix 2); Step 2) evaluation of the impact of digitalisation tools (Y_{iP}; Appendix 1) on the chosen SCOR performance indicators; Step 3) evaluation of the SARS-CoV-2-pandemic specific impact on supply chain areas; Step 4) evaluation of the predictive (p_{iI}) as well as reactive (r_{iI}) assistance of the digital tools in these areas (Z_{iI}) (see Figure 2).

Figure 2. Methodological approach



We evaluated the individual impacts either in a binary mode (0 = no impact; 1 = impact) or in a stepwise manner between 0 and 1 (0 = not applicable; 1 = fully applicable; .33 = somewhat applicable and .66 = mostly applicable)[1]. Overall, our scoring model assesses the suitability of a technology for a specific key performance indicator as well as the impact for a specific supply chain area. By doing so, we were able to see whether and which digital tool affects a supply chain area and whether

[1] The results of these four steps are presented in the appendix.

reactive or preventive measures are possible. E.g., data and analytics allow transparency in the upstream supply chain and consequently helps when experiencing problems within sourcing, while its value to solve problems in the staff area is very limited (See Appendix 3).

When it comes to the performance indicators, we experienced that digital automation has higher effects on the cost structure than data and analytics (see Appendix 1). As for the overall evaluation, we identified that digitalisation has a great power to serve as a reactive countermeasure for sourcing problems, while mechanical automation has no value (see Appendix 4).

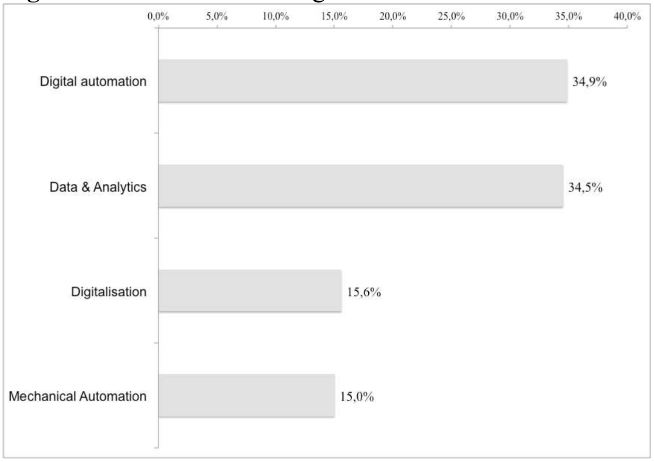
Our methodological approach followed the notions by Moore and Baker (1969) who suggested multiple criteria scoring methods as adequate methods to evaluate different proposals, where decision makers use data of different quality for decision making. The data stems from analysing the relevant literature and three expert interviews with senior consultants of an international consultancy company. Each of the interviewed experts has more than 10 years of professional experience in their fields.

The interviews covered following areas: a) recent consequences of the SARS-CoV-2 pandemic in general as well as the particular effects for companies, b) the usefulness and applicability of key performance indicator models, c) the value of digital tools for counteracting the pandemic consequences. The interviews took between 45 and 60 minutes and were based on interview guidelines with open ended questions which followed the guiding research questions. For all interviews, we prepared protocols that were returned to the interviewed person for validation of our collected information. The generated data was qualitatively analysed following the notions of Mayring and Fenzl (2019).

4. RESULTS

Figure 3 shows the overall results on the adequacy of the examined digital tools for stabilising a supply chain against the pandemic and indicates the power of digital automation as well as data & analytics.

Figure 3. Overall value of digital tools



The identified scores result from cumulating the partial scoring values across all key performance indicators and affected supply chain areas. Digital automation as well as data & analytics are identified as the best fitting digital tools as lack of transparency along the supply chain was considered to be a heavy problem. Regarding the affected supply chain areas, we were able to see limitations of digital automation in the staff area. Furthermore, data & analytics were not assessed.

The stabilising effects of the digital tools on the various supply chain areas are outlined in Figure 4. There we see that the area of staff is affected most by digital automation, followed by digitalisation in the sourcing and data & analytics in the demand area.

The total technology relevancy for the performance indicators, where we see that data & analytics achieves the highest evaluation results when reducing costs and improving the asset situation are shown in Figure 5. Furthermore, digital automation positively affects costs as well as throughput times.

Figure 4. Detailed score results within the examined supply chain areas

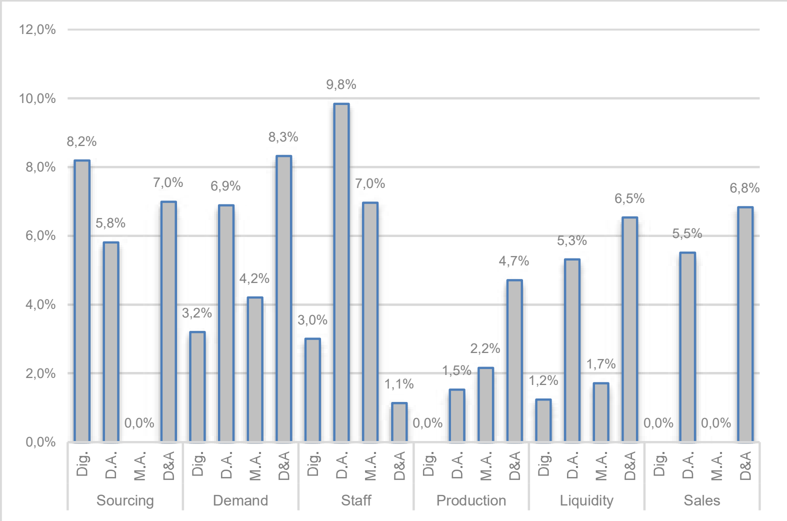


Figure 5. Technology relevance for performance indicators

	Dig.	D.A.	M.A.	D&A		Dig.	D.A.	M.A.	D&A
RL.1.1	1.66	3.145	1.3134	2.5245	**CO.1.1**	1.825	3.805	1.5312	4.825
RL.2.1	1.33	1.66	0.66	1.165	*CO.2.1*	1.33	1.485	0	2.66
RL.2.2	1.66	3.145	1.3134	2.5245	*CO.2.2*	1.33	1.32	0.2178	2
RL.2.3	0.33	1	0	0.1089	*CO.2.3*	1.0956	2.485	1.3134	2.825
RL.2.4	0.1089	0.7689	0.4389	0	*CO.2.4*	0.1089	1.32	0.4356	1.32
RS.1.1	1.825	3.805	1.5312	3.1845	*CO.2.5*	0.165	1.485	0.2178	1.7556
RS.2.1	0.9867	1.98	0.3267	3	*CO.2.6*	0.49335	0.92565	0	4.66
RS.2.2	0.66	1.825	1.99	1.2045	*CO.2.7*	0.33	1.485	0.99	0.8778
RS.2.3	0.33	1.32	0.2178	1.32	**CO.1.2**	1.66	2.485	1.3134	0.93225
AG.1.1	0.9867	3.145	1.0956	2.5245	*CO.2.3*	0.66	1.825	1.3134	0.60225
AG.2.1	1.165	1.32	0.2178	1.32	**AM.1.1**	1.825	3.805	1.5312	4.825
AG.2.2	0.1089	0.38445	1.33	0.5445	*AM.2.1*	0.495	1.98	0	1.98
AG.2.3	0.1089	1.2045	0.4389	1.825	*AM.2.2*	0.49335	1.8513	1.32	4.66
AG.2.4	0.9867	2.32	0.8778	0	*AM.2.3*	0.825	2.98	0	3.165
AG.2.5	0.3267	2.32	0.8778	1.4289	**AM.1.2**	1.2045	2.5113	1.5312	3.1845
AG.1.3	0.3267	1.0956	0.8778	0.7689	-	0.1089	0.9801	0.3267	2.66
AG.2.11	0.1089	0.4356	0.1089	1	*CO.1.1*	1.825	2.5113	1.5312	3.1845
AG.2.12	0.16335	0.5478	1.33	0.38445	*CO.1.2*	1.66	2.485	1.3134	0.93225
AG.2.13	0.1089	0.4356	0	0	*AM.2.5*	0.49335	0.6534	0.6534	1.98
					AM.1.3	1.825	3.805	1.5312	1.59225
					CO.1.1	1.825	3.805	1.5312	1.59225

5. CONCLUSION

In this paper, we examined how unexpected disturbances, such as the SARS-CoV-2-pandemic, affects supply chain stability and how digital tools are able to react and counteract to such turbulences. For solving this problem, we developed a conceptual model where we identified six supply chain areas that can be affected by SARS-CoV-2. In order to measure stability in these areas as well as to evaluate the consequences, we used the SCOR approach and its measures as the model focuses on a complete chain and the first two levels SCOR performance indicators were considered acceptable for our measuring purpose. While performing our study, McCrea (2021) discusses how the pandemic accelerated supply chain visibility, digitalisation and automation, whereas Mitchel (2021) shows recently that managers perceive the pandemic as an accelerator for the complete digital transformation of their supply chains. Consequently, both results support the overall results of our study.

Out of a number of SCM-relevant digitalisation technology (as suggested by Hoberg et al. 2019), we focused on several SCM areas in which different digital tools - data & analytics, digitalisation, digital automation as well as mechanic automation - can help in reacting and preventing disturbances due to their possibilities of scaling, low downtimes, independence from employees and potential transparency for decision making.

Our findings show that data & analytics and digital automation have the greatest impact based on their cost-efficient scalability and transparency. However, digital automation follows digitalisation. The effects by mechanical automation are low as its scalability is limited and it offers no transparency advantages.

There are also some disadvantages that need to be considered, which refer to the acquisition and implementation costs of technology as well as to their opportunity costs. Even though digital transformation is seen as a major driver for the competitiveness of a firm, we need to refer to the low level of digital transformation so far. There are problems, challenges and barriers that need to be dealt with. Another limitation of this work is the high level of abstraction, which makes it difficult to evaluate cross-industry cost models for implementing the model. Besides this, different regional as well as national differences in digitalisation, data protection and subsidies need to be considered.

Future research should add a cost-benefit analysis to our utility analysis as well as an industry-specific examination of the validity of our approach.

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Appendix 1: Evaluation of the positive effects of digitalisation on SCOR performance indicators (Y_{IP}) (1 = Digitalisation; 2 = Digital Automation; 3 = Mechanical Automation; 4 = Data & Analytics)

KPI	Description	1	2	3	4
RL.1.1	Perfect Order Fulfillment	1	1	.66	.66
RL.2.1	% of Orders Delivered in Full	1	1	.66	1
RL.2.2	Delivery Performance to Customer Commit Date	1	1	.66	.66
RL.2.3	Documentation Accuracy	1	1	0	.66
RL.2.4	Perfect Condition	.33	.66	.33	0
RS.1.1	Order Fulfillment Cycle Time	1	1	.66	.66
RS.2.1	Source Cycle Time	.66	1	.33	1
RS.2.2	Make Cycle Time	1	1	1	.66
RS.2.3	Delivery Cycle Time	1	1	.33	.66
AG.1.1	Upside Supply Chain Flexibility	.66	1	.66	.66
AG.2.1	Upside Source Flexibility	1	1	.66	.66
AG.2.2	Upside Make Flexibility	.33	.33	1	.66
AG.2.3	Upside Deliver Flexibility	.33	.66	.33	1
AG.2.4	Upside Source Return Flexibility	.66	1	.66	0
AG.2.5	Upside Deliver Return Flexibility	.66	1	.66	.66
AG.1.3	Downside Supply Adaptability	.66	.66	.66	.66
AG.2.11	Downside Source Adaptability	.66	.66	.33	1
AG.2.12	Downside Make Adaptability	.33	.33	1	.33
AG.2.13	Downside Deliver Adaptability	.66	.66	0	0
CO.1.1	Total Supply Chain Management Cost	1	1	.66	1
CO.2.1	Cost to Plan	1	1	0	1
CO.2.2	Cost to Source	1	1	.33	1
CO.2.3	Cost to Make (CO.1.2)	.66	1	.66	1
CO.2.4	Cost to Deliver	.33	1	.66	.66
CO.2.5	Cost to Return	1	1	.33	.66
CO.2.6	Value At Risk (VAR $. % of Sales)	.33	.33	0	1
CO.2.7	Mitigation Cost (Cost To Mitigate Supply Chain)	1	1	1	.33
CO.1.2	Cost of Goods Sold (COGS)	1	1	.66	.33
CO.2.3	Cost to Make	1	1	.66	.33
AM.1.1	Cash-to-Cash Cycle Time	1	1	.66	1
AM.2.1	Days Sales Outstanding	1	1	0	.66
AM.2.2	Inventory Days of Supply	.33	.66	1	1
AM.2.3	Days of Payable Outstanding	1	1	0	1
AM.1.2	Return on Supply Chain Fixed Assets	.66	.66	.66	.66
-	Supply Chain Revenue	.33	.66	.33	1
CO.1.1	Supply Chain Management Costs	1	.66	.66	.66
CO.1.2	Cost of Goods Sold	1	1	.66	.33
AM.2.5	Supply Chain Fixed Assets	.33	.33	.66	.66
AM.1.3	Return on Working Capital	1	1	.66	.33
CO.1.1	Supply Chain Management Costs	1	1	.66	.33

Appendix 2: Results on the evaluation of the CoV-2-pandemic specific impact on supply chain areas (1 = sourcing; 2 = demand; 3 = staff; 4 = production; 5 = liquidity; 6 = sales)

KPI	Description	1	2	3	4	5	6
RL.1.1	Perfect Order Fulfillment	1	1	1	1		1
RL.2.1	% of Orders Delivered in Full	1		1			
RL.2.2	Delivery Performance to Customer Commit Date	1	1	1	1		1
RL.2.3	Documentation Accuracy			1			
RL.2.4	Perfect Condition			1	1		
RS.1.1	Order Fulfillment Cycle Time	1	1	1	1	1	1
RS.2.1	Source Cycle Time	1	1			1	
RS.2.2	Make Cycle Time		1	1	1		
RS.2.3	Delivery Cycle Time		1				1
AG.1.1	Upside Supply Chain Flexibility	1		1	1	1	1
AG.2.1	Upside Source Flexiblity	1				1	
AG.2.2	Upside Make Flexibility			1	1		
AG.2.3	Upside Deliver Flexibility			1	1		1
AG.2.4	Upside Source Return Flexibility	1		1		1	
AG.2.5	Upside Deliver Return Flexibility			1		1	1
AG.1.3	Downside Supply Adaptability			1		1	
AG.2.11	Downside Source Adaptability					1	
AG.2.12	Downside Make Adaptability			1		1	
AG.2.13	Downside Deliver Adaptability					1	
CO.1.1	Total Supply Chain Management Cost	1	1	1	1	1	1
CO.2.1	Cost to Plan	1	1		1		
CO.2.2	Cost to Source	1	1				
CO.2.3	Cost to Make (CO.1.2)	1	1	1	1		
CO.2.4	Cost to Deliver		1				1
CO.2.5	Cost to Return				1	1	1
CO.2.6	Value At Risk (VAR $. % of Sales)	1	1		1	1	1
CO.2.7	Mitigation Cost (Cost To Mitigate Supply Chain)		1		1		1
CO.1.2	Cost of Goods Sold (COGS)	1	1	1	1		
CO.2.3	Cost to Make		1	1	1		
AM.1.1	Cash-to-Cash Cycle Time	1	1	1	1	1	1
AM.2.1	Days Sales Outstanding		1			1	1
AM.2.2	Inventory Days of Supply	1	1		1	1	1
AM.2.3	Days of Payable Outstanding		1	1		1	1
AM.1.2	Return on Supply Chain Fixed Assets	1	1	1	1	1	1
-	Supply Chain Revenue		1		1		1
CO.1.1	Supply Chain Management Costs	1	1	1	1	1	1
CO.1.2	Cost of Goods Sold	1	1	1	1		
AM.2.5	Supply Chain Fixed Assets	1	1			1	
AM.1.3	Return on Working Capital	1	1	1	1	1	1

CO.1.1	Supply Chain Management Costs	1	1	1	1	1	1

Appendix 3: Results on the evaluation evaluation of the predictive (p_{iI}) as well as reactive (r_{iI}) assistance of the digital tools in these areas (Z_{iI}) (1 = sourcing; 2 = demand; 3 = staff; 4 = production; 5 = liquidity; 6 = sales)

Digital tool	**1**	**2**	**3**	**4**	**5**	**6**
Digitalisation	1	.33	.66	0	.33	0
Preventive	.5	.5	0	0	.5	0
Reactive	.5	.5	.5	0	0	0
Digital Automation	.66	.66	1	.33	.66	.66
Preventive	.5	.5	.5	0	.5	.5
Reactive	.5	.5	.5	.5	.5	.5
Mechanical Automation	0	.66	1	.33	.33	0
Preventive	0	.5	.5	.5	.5	0
Reactive	0	.5	.5	.5	.5	0
Data & Analytics	1	1	.33	.66	1	1
Preventive	.5	.5	0	.5	.5	.5
Reactive	.5	.5	.5	.5	.5	.5

Appendix 4: Total results

P	A	Sourcing				Demand				Staff			
	i	Digitalisation	Digital Automation	Mechanical Automation	Data & Analytics	Digitalisation	Digital Automation	Mechanical Automation	Data & Analytics	Digitalisation	Digital Automation	Mechanical Automation	Data & Analytics
	Z_{ik}	*1*	*.66*	*0*	*1*	*.33*	*.66*	*.66*	*1*	*.66*	*1*	*1*	*.33*
	p_{ik}	*.5*	*.5*	*0*	*.5*	*.5*	*.5*	*.5*	*.5*	*0*	*.5*	*.5*	*0*
	r_{ik}	*.5*	*.5*	*0*	*.5*	*.5*	*.5*	*.5*	*.5*	*.5*	*.5*	*.5*	*.5*
RL.1.1		1	.66	0	.66	.33	.66	.4356	.66	.33	1	.66	.1089
RL.2.1		1	.66	0	1	0	0	0	0	.33	1	.66	.165
RL.2.2		1	.66	0	.66	.33	.66	.4356	.66	.33	1	.66	.1089
RL.2.3		0	0	0	0	0	0	0	0	.33	1	0	.1089
RL.2.4		0	0	0	0	0	0	0	0	.1089	.66	.33	0
RS.1.1		1	.66	0	.66	.33	.66	.4356	.66	.33	1	.66	.1089
RS.2.1		.66	.66	0	1	.2178	.66	.2178	1	0	0	0	0
RS.2.2		0	0	0	0	.33	.66	.66	.66	.33	1	1	.1089
RS.2.3		0	0	0	0	.33	.66	.2178	.66	0	0	0	0
AG.1.1		.66	.66	0	.66	0	0	0	0	.2178	1	.66	.1089
AG.2.1		1	.66	0	.66	0	0	0	0	0	0	0	0
AG.2.2		0	0	0	0	0	0	0	0	.1089	.33	1	.1089
AG.2.3		0	0	0	0	0	0	0	0	.1089	.66	.33	.165
AG.2.4		.66	.66	0	0	0	0	0	0	.2178	1	.66	0
AG.2.5		0	0	0	0	0	0	0	0	.2178	1	.66	.1089
AG.1.3		0	0	0	0	0	0	0	0	.2178	.66	.66	.1089
AG.2.11		0	0	0	0	0	0	0	0	0	0	0	0
AG.2.12		0	0	0	0	0	0	0	0	.1089	.33	1	.05445
AG.2.13		0	0	0	0	0	0	0	0	0	0	0	0
CO.1.1		1	.66	0	1	.33	.66	.4356	1	.33	1	.66	.165
CO.2.1		1	.66	0	1	.33	.66	0	1	0	0	0	0
CO.2.2		1	.66	0	1	.33	.66	.2178	1	0	0	0	0
CO.2.3		.66	.66	0	1	.2178	.66	.4356	1	.2178	1	.66	.165
CO.2.4		0	0	0	0	.1089	.66	.4356	.66	0	0	0	0
CO.2.5		0	0	0	0	0	0	0	0	0	0	0	0
CO.2.6		.33	.2178	0	1	.1089	.2178	0	1	0	0	0	0
CO.2.7		0	0	0	0	.33	.66	.66	.33	0	0	0	0
CO.1.2		1	.66	0	.33	.33	.66	.4356	.33	.33	1	.66	.05445
CO.2.3		0	0	0	0	.33	.66	.4356	.33	.33	1	.66	.05445
AM.1.1		1	.66	0	1	.33	.66	.4356	1	.33	1	.66	.165
AM.2.1		0	0	0	0	.33	.66	0	.66	0	0	0	0
AM.2.2		.33	.4356	0	1	.1089	.4356	.66	1	0	0	0	0
AM.2.3		0	0	0	0	.33	.66	0	1	.33	1	0	.165
AM.1.2		.66	.4356	0	.66	.2178	.4356	.4356	.66	.2178	.66	.66	.1089
-		0	0	0	0	.1089	.4356	.2178	1	0	0	0	0
CO.1.1		1	.4356	0	.66	.33	.4356	.4356	.66	.33	.66	.66	.1089
CO.1.2		1	.66	0	.33	.33	.66	.4356	.33	.33	1	.66	.05445
AM.2.5		.33	.2178	0	.66	.1089	.2178	.4356	.66	0	0	0	0
AM.1.3		1	.66	0	.33	.33	.66	.4356	.33	.33	1	.66	.05445
CO.1.1		1	.66	0	.33	.33	.66	.4356	.33	.33	1	.66	.05445

P	A	Production				Liquidity				Sales			
	i	*Digitalisation*	*Digital Automation*	*Mechanical Automation*	*Data & Analytics*	*Digitalisation*	*Digital Automation*	*Mechanical Automation*	*Data & Analytics*	*Digitalisation*	*Digital Automation*	*Mechanical Automation*	*Data & Analytics*
	Z_{iA}	*0*	*.33*	*.33*	*.66*	*.33*	*.66*	*.33*	*1*	*0*	*.66*	*0*	*1*
	p_{iA}	*0*	*0*	*.5*	*.5*	*.5*	*.5*	*.5*	*.5*	*0*	*.5*	*0*	*.5*
	r_{iA}	*0*	*.5*	*.5*	*.5*	*0*	*.5*	*.5*	*.5*	*0*	*.5*	*0*	*.5*
RL.1.1		0	.165	.2178	.4356	0	0	0	0	0	.66	0	.66
RL.2.1		0	0	0	0	0	0	0	0	0	0	0	0
RL.2.2		0	.165	.2178	.4356	0	0	0	0	0	.66	0	.66
RL.2.3		0	0	0	0	0	0	0	0	0	0	0	0
RL.2.4		0	.1089	.1089	0	0	0	0	0	0	0	0	0
RS.1.1		0	.165	.2178	.4356	.165	.66	.2178	.66	0	.66	0	.66
RS.2.1		0	0	0	0	.1089	.66	.1089	1	0	0	0	0
RS.2.2		0	.165	.33	.4356	0	0	0	0	0	0	0	0
RS.2.3		0	0	0	0	0	0	0	0	0	.66	0	.66
AG.1.1		0	.165	.2178	.4356	.1089	.66	.2178	.66	0	.66	0	.66
AG.2.1		0	0	0	0	.165	.66	.2178	.66	0	0	0	0
AG.2.2		0	.05445	.33	.4356	0	0	0	0	0	0	0	0
AG.2.3		0	.1089	.1089	.66	0	0	0	0	0	.4356	0	1
AG.2.4		0	0	0	0	.1089	.66	.2178	0	0	0	0	0
AG.2.5		0	0	0	0	.1089	.66	.2178	.66	0	.66	0	.66
AG.1.3		0	0	0	0	.1089	.4356	.2178	.66	0	0	0	0
AG.2.11		0	0	0	0	.1089	.4356	.1089	1	0	0	0	0
AG.2.12		0	0	0	0	.05445	.2178	.33	.33	0	0	0	0
AG.2.13		0	0	0	0	.1089	.4356	0	0	0	0	0	0
CO.1.1		0	.165	.2178	.66	.165	.66	.2178	1	0	.66	0	1
CO.2.1		0	.165	0	.66	0	0	0	0	0	0	0	0
CO.2.2		0	0	0	0	0	0	0	0	0	0	0	0
CO.2.3		0	.165	.2178	.66	0	0	0	0	0	0	0	0
CO.2.4		0	0	0	0	0	0	0	0	0	.66	0	.66
CO.2.5		0	.165	.1089	.4356	.165	.66	.1089	.66	0	.66	0	.66
CO.2.6		0	.05445	0	.66	.05445	.2178	0	1	0	.2178	0	1
CO.2.7		0	.165	.33	.2178	0	0	0	0	0	.66	0	.33
CO.1.2		0	.165	.2178	.2178	0	0	0	0	0	0	0	0
CO.2.3		0	.165	.2178	.2178	0	0	0	0	0	0	0	0
AM.1.1		0	.165	.2178	.66	.165	.66	.2178	1	0	.66	0	1
AM.2.1		0	0	0	0	.165	.66	0	.66	0	.66	0	.66
AM.2.2		0	.1089	.33	.66	.05445	.4356	.33	1	0	.4356	0	1
AM.2.3		0	0	0	0	.165	.66	0	1	0	.66	0	1
AM.1.2		0	.1089	.2178	.4356	.1089	.4356	.2178	.66	0	.4356	0	.66
-		0	.1089	.1089	.66	0	0	0	0	0	.4356	0	1
CO.1.1		0	.1089	.2178	.4356	.165	.4356	.2178	.66	0	.4356	0	.66
CO.1.2		0	.165	.2178	.2178	0	0	0	0	0	0	0	0
AM.2.5		0	0	0	0	.05445	.2178	.2178	.66	0	0	0	0
AM.1.3		0	.165	.2178	.2178	.165	.66	.2178	.33	0	.66	0	.33
CO.1.1		0	.165	.2178	.2178	.165	.66	.2178	.33	0	.66	0	.33