Supply Chain Forum: An International Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tscf20

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SUPPLY CHAIN FORUM: AN INTERNATIONAL JOURNAL
https://doi.org/10.1080/16258312.2021.1934106

Application areas and antecedents of automation in logistics and supply chain management: a conceptual framework

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ABSTRACT

One of the main challenges for modern logistics and supply chain management (LSCM) is the automation of processes along the supply chain. Although research on different automation applications in LSCM exists, LSCM managers lack an overall picture of possible application areas as well as the antecedents influencing the successful implementation of applications. The study applied data triangulation through a systematic literature review of 265 articles and a Nominal Group Technique exercise among 18 LSCM professionals in order to extract automation application areas as well as antecedents of successful automation projects. Through a structured synthesis process building on the Q-methodology a conceptual framework of application areas and antecedents of automation in LSCM is proposed. The framework synthesises ten application areas of automation in LSCM and ten antecedents that influence the efficient implementation and use of automation applications. The study proposes that the impact of *technological* and *informational antecedents* is moderated by *organisational* as well as *knowledge-related antecedents*, and advances propositions outlining the impact of antecedents on the successful implementation and use of automation applications. The study provides a coherent conceptualisation of automation in LSCM which provides a common basis on which to merge further discussions on automation between research and practice.

KEYWORDS

Automation; autonomous logistics; digitalisation; systematic literature review; nominal group technique

Introduction

In an era of digitalisation, the automation of physical and informational processes in logistics and supply chain management (LSCM) is one of the most important challenges that LSCM practitioners have to prepare for (Kersten et al. 2017). This is, in part, due to the increasing cost pressure that LSCM has faced for years (Handfield et al. 2013; Kersten et al. 2017), but also because the lack of qualified LSCM personnel drives companies to pursue technological progress through automation (Klumpp 2018). Although the need for automation in LSCM has existed for years, the Coronavirus pandemic has further exacerbated this need, thus making the automation of LSCM processes into one of the major challenges for future logistics networks in the wake of the pandemic (Straube and Nitsche 2020; Govindan, Mina, and Alavi 2020; Ralston and Blackhurst 2020; Belhadi et al. 2021). Although practitioners acknowledge the importance of this vital topic, companies admit that they are facing difficulties in adapting their LSCM processes and environments to meet automation requirements, and they need further assistance (Kersten et al. 2017; Junge et al. 2019).

From a research perspective, various researchers have emphasised the importance of automation for LSCM over recent years (S. Min, Zacharia, and Smith 2019; Schniederjans, Curado, and Khalajhedayati 2019; Jämsä-Jounela 2007; Huhns, Stephens, and Ivezic 2002; Viswanadham 2002). Owing to the ever-increasing technologization and digitalisation of logistics processes, automated and autonomous control of logistics systems has become possible over the past two decades, and researchers have proposed several decision architectures to achieve this. Hence, the automation of decision processes plays a vital role in self-organised supply chains, and authors such as Ounnar et al. (2004) have proposed decision architectures that build upon decision architectures for the control of production systems (Hendrik et al. 1998). Since decisions in LSCM often pose problems that affect multiple levels, multicriteria decision-making approaches have also been proposed for supply-network control (Dubromelle, Ounnar, and Pujo 2012), supplier selection (Muralidharan, Anantharaman, and Deshmukh 2002; Ounnar et al. 2018), and many other decision problems.

In particular, the vision of self-organising and autonomous logistics systems, in which almost all processes run automatically, has gained in importance over the last ten years. This is primarily due to various technological trends, running in parallel, that make such systems appear feasible. The concept of the Physical Internet, introduced by Montreuil (2011), called for new ways of connecting physical objects in global value chains to the internet and thereby enabling

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new design opportunities and new concepts of collaborative logistics systems. From that emerged several research studies aiming at the interconnection of logistics services (e.g., Pan et al. 2017), efficient control of logistics systems by integrating smart containers (e.g., Sallez et al. 2016), and many more. In the development of new control mechanisms for logistics networks, made possible by technological progress, the concept of cyber-physical systems (Cardin 2017) or, in this context, cyber-physical logistics systems (Pujo and Ounnar 2018) is also significant. Such systems aim to enable individual objects to have more decentralised decision-making authority through real-time data availability, thereby leading to a constant reconfiguration of those systems, either in intralogistics (Pujo et al. 2016), logistics networks (Pujo and Ounnar 2018), production environments (Monostori 2014; Uhlemann et al. 2017), or other fields.

Mooney, Gurbaxani, and Kraemer (1996) categorise automation-driven changes into first-, second-, and third-order changes. While first-order changes imply the automation of particular operational processes, second-order changes result in the automation of managerial processes due to the availability of a variety of information on operational processes. In contrast, third-order changes result in new capabilities of the focal firm and new ways of doing business (Mooney, Gurbaxani, and Kraemer 1996). Min, Zacharia, and Smith (2019) identify 'industry 4.0' and anticipatory shipping as possible outcomes of third-order changes, but autonomous logistics systems are also conceivable.

While the automation of operational processes in LSCM is already taking place, building a basis for future autonomous logistics systems, Junge et al. (2019) suggest that fully autonomous handling of the most important operational logistics functions will be possible in around ten years. To facilitate the required changes necessary for this fast-paced transformation, LSCM managers need assistance. However, conceptual research that seeks to contribute to better understanding the automation construct is sparse (Wu et al. 2016). Research in this field mainly focuses on specific automation applications in LSCM, leading to several solutions beneficial to practice (e.g., forecasting: cf. Küsters, McCullough, and Bell 2006; Nikolopoulos, Zied Babai, and Bozos 2016), and on specific technologies and their effect on the automation of processes (e.g., artificial intelligence: cf. H. Min 2010). In order to provide LSCM practitioners with further assistance and to help them to converge with researchers' vital discussions, both sides need to understand better the full picture of automation application areas as well as the antecedents contributing to the efficient implementation and use of automation applications in LSCM. Therefore, this study seeks to answer the following research questions:

RQ1: What are the application areas of automation in LSCM?

RQ2: What are the antecedents of automation in LSCM and how do they impact the efficient implementation and use of automation projects?

This study aims at developing a conceptual framework that outlines possible application areas of automation in LSCM as well their antecedents. Efficient implementation and use of an automation application is here understood as setting up an automation application, with time and cost under control, and having it utilised by the user in its intended way. To answer the above research questions and to contribute to research-practice discussions on this topic, the study performs data triangulation by combining a systematic literature review (SLR) of 265 LSCM articles with a group exercise applying the Nominal Group Technique (NGT) (Van De Ven and Delbecq 1971; Delbecq and Van De Ven 1971) among 18 SCM professionals to integrate perspectives from research and practice on this topic.

The remainder of this article is structured as follows. First, we introduce to the topic of automation and outline different definitions and understandings of automation wherefrom we conclude with a definition of logistics and supply chain automation. Second, the research design is described in detail by outlining the procedure of the systematic literature review as well as the NGT group exercise and how we tried to limit bias throughout the whole process. Third, the resulting conceptual framework is explained including the description of antecedents of successful logistics and supply chain automation. Finally, the implications for research and practice are discussed.

Introduction to automation and study focus

When manufacturers initially introduced automation into production, it was specifically for the mass production of automobiles. However, automation gradually evolved to encompass the global network and relationships of a company (Viswanadham 2002). As a result, definitions and understandings of automation evolved in the production literature. Table 1 presents an overview of the understandings and definitions found in this literature.

By reading those definitions and understandings it becomes obvious that replacing a task performed by a human being with a machine or a computer is the focus of automation. During the early stages of automation in production this mainly meant that a machine is replacing or supporting a human being to fulfill the task more efficiently and safely, but also to perform a task that the human could not handle (e.g. lifting heavy components). Due to the advancing industrialisation and digitalisation, the aspect of supporting tasks that humans alone cannot solve

Table 1. Understandings and definitions of automation.

Authors	Definition/understanding of automation
Bainbridge (1983, 775)	"The classic aim of automation is to replace human manual control, planning and problem solving by automatic devices and computers".
Sheridan (1992, 3)	"Automation is the automatically controlled operation of an apparatus, a process or a system by mechanical or electronic devices that take the place of human organs of observation, decision and effort".
Parasuraman and Riley (1997, p. 231)	'We define automation as the execution by a machine agent (usually a computer) of a function that was previously carried out by a human'.
Parasuraman, Sheridan, and Wickens (2000, p. 287)	'In our definition, automation refers to the full or partial replacement of a function previously carried out by the human operator'.

becomes even more important. In modern supply chains, intelligent algorithms support decision making and make problems solvable that would be too complex for humans alone. Therefore, operations research is an integral part of research in the field of logistics and supply chain automation since it addresses the support of very complex decisions by means of advanced analytics.

To strengthen the focus of the review and to assist the SLR in identifying appropriate literature, a definition adapted to the specifics of LSCM is necessary. To the best of the authors' knowledge, there was no such previous, extant definition. Taking the general definitions of automation from Table 1 into account alongside the specifics of LSCM, we propose the following definition as a basis for this study:

> *Logistics and supply chain automation is defined as the partial or full replacement or support of a human-performed physical or informational process by a machine. This includes tasks to plan, control or execute the physical flow of goods as well as the corresponding informational and financial flows within the focal firm and with supply chain partners.*

The proposed definition of logistics and supply chain automation includes autonomous logistics but does not restrict automation to this. Autonomous logistics systems are understood as systems in which non-human actors (e.g., software agents) make decisions independently without the need for human intervention. For many automation applications, decision support is given but humans are in control of the actual decision.

To set the conceptual constraints of this study, the scope includes all LSCM-related processes that are being automated or could be automated including production logistics (i.e. supplying production machines with materials) (Nyhuis and Wiendahl 2009) but excludes direct production processes. Since the automation of production processes is different from automation in LSCM because of its closed environment, it remains a different field of research and is thereby excluded from this investigation. The unit of analysis is the focal firm that is seeking to implement automation applications, and the level of analysis is the SC with which the focal firm is dealing (Yurdusev 1993).

Research design

In order to outline the application areas of automation in LSCM and to synthesise the antecedents that are driving the success of LSCM automation projects, data triangulation was performed. Based on the approach of Nitsche and Durach (2018), the authors performed an SLR comprising 265 articles and combined this with the results of a group exercise applying the NGT among 18 SC professionals. Although a variety of literature was available on certain LSCM automation applications, the integration of the group exercise allowed the research to achieve wider practical insights. Subsequently, both data collection streams were integrated to synthesise the application areas and antecedents of automation in LSCM. Combining both streams of data collection identified 424 application areas and 274 antecedents (including duplicates). Through a structured synthesis process building on the Q-methodology (Ellingsen, Størksen, and Stephens 2010), the authors developed a proposed conceptual framework of automation in LSCM that synthesises the application areas and antecedents of automation in LSCM from the perspectives of research and practice. Figure 1 outlines the overall research procedure.

Systematic literature review

Conducted rigorously, SLRs in LSCM research can assist in synthesising widespread knowledge in order to advance current research in a field (Christian F. Durach, Kembro, and Wieland 2017; Christian F. Durach 2016). To achieve this, this study followed the six-step procedure for SLRs in LSCM proposed by Durach (2016), as applied by Nitsche and Durach (2018). After determining the scope of this study, the authors crafted three distinct inclusion criteria in preparation for the literature search (see Table 2). To ensure the inclusion of high-quality research only, the literature search was restricted to peer-reviewed journals (cf. Hohenstein et al. 2015; Habib, Bastl, and Pilbeam 2015).

For the literature search, as Durach (2016) proposed, the authors chose two different databases, Business Source Complete (by EBSCO) and Social Science Citation Index (via ISI Web of Knowledge), to identify a comprehensive set of literature. To reduce bias, eight independent LSCM researchers contributed to crafting the search string. These researchers were asked to provide keywords that they deemed appropriate for

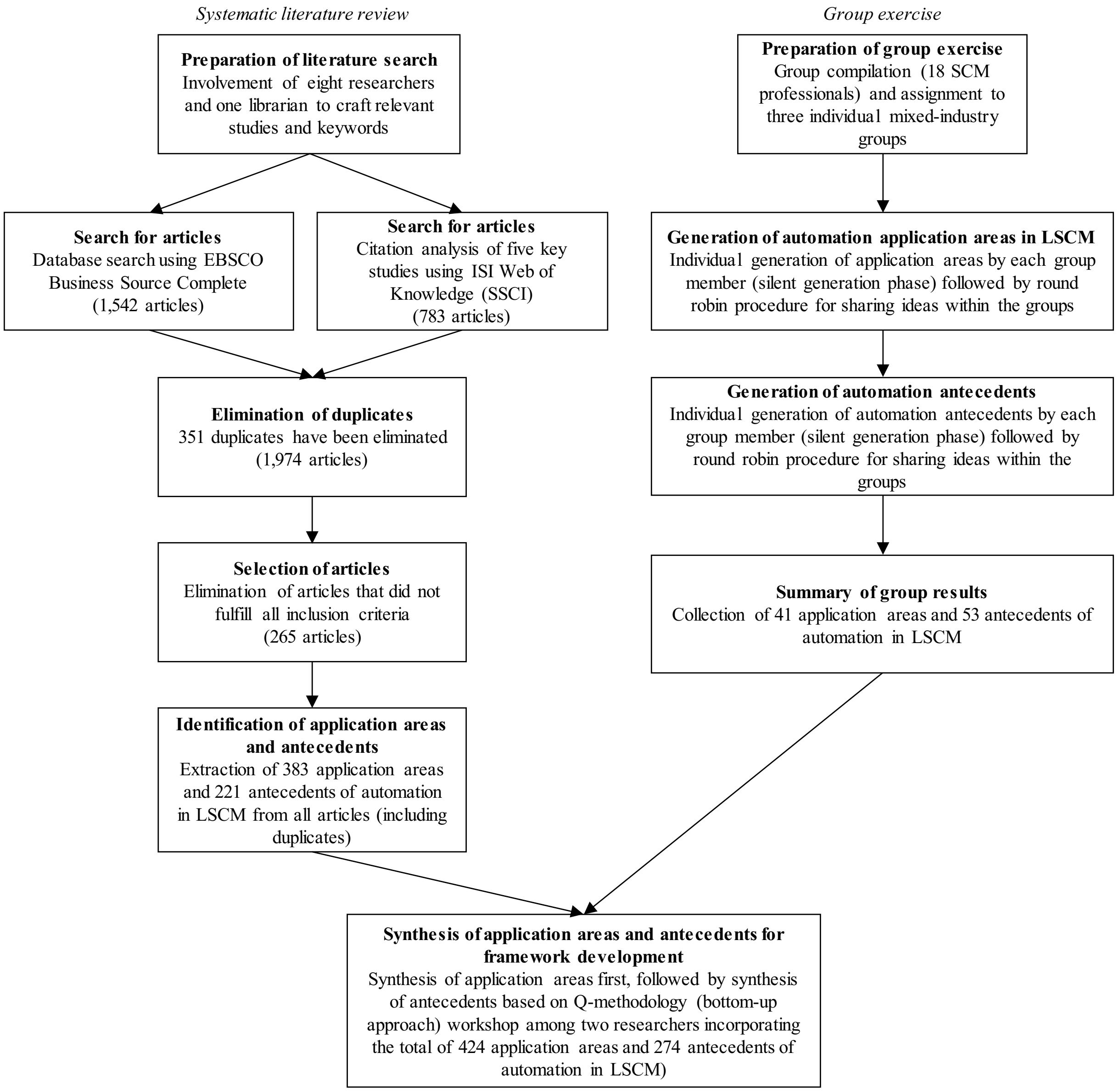

Figure 1. Research procedure.

Table 2. Inclusion criteria.

Inclusion Criterion	Rationale
Title and abstract provide an indication that the article covers automation application(s) in LSCM.	This is necessary to ensure that the paper deals with automation in LSCM according to the proposed definition of logistics and supply chain automation.
Title and abstract indicate that automation applications and/or antecedents of implementing automation applications are discussed.	The goal of the literature review was to identify application areas and antecedents of automation in LSCM.
The article is written in English	English is the prevalent language in LSCM research

identifying literature dealing with the application areas and antecedents of automation in LSCM and to propose a search string combining these keywords. Two authors evaluated the input provided to further reduce bias and one independent librarian assisted them in developing the final search string, which was further adjusted to the specific syntax of each literature database (see Table 3).

Table 3. Search string for the database search.

Business Source Complete (by EBSCO)	(TI ('automat*' OR 'autonomous*' OR 'robot*' OR 'artificial intelligence' OR 'AI' OR 'multi-agent') OR AB ('automat*' OR 'autonomous*' OR 'robot*' OR 'artificial intelligence' OR 'AI' OR 'multi-agent') OR SU ('automat*' OR 'autonomous*' OR 'robot*' OR 'artificial intelligence' OR 'AI' OR 'multi-agent') OR KW ('automat*' OR 'autonomous*' OR 'robot*' OR 'artificial intelligence' OR 'AI' OR 'multi-agent')) AND (TI ('logistics' OR ' supply chain*' OR 'supplier*') OR AB ('logistics' OR ' supply chain*' OR 'supplier*') OR SU ('logistics' OR ' supply chain*' OR "supplier*) OR KW ('logistics' OR ' supply chain*' OR 'supplier*'))
ISI Web of Knowledge (SSCI)	TS = ('automat*' OR 'autonomous*' OR 'robot*' OR 'artificial intelligence' OR 'AI' OR 'multi-agent') AND TS = ('logistics' OR ' supply chain*' OR 'supplier*')

AB: Abstract Search; TI: Title Search; KW: Keywords; SU: Subject Term; TS: Topic Search (includes title, abstract, author keywords and keywords plus

Table 4. Sample demographics for the group exercise.

Industry	Total number of employees	Revenue	management level of participant	Professional experience of participant in LSCM (years)
Logistics service provider	above 2000	above 5 bn €	Team leader	13
Logistics service provider	above 2000	above 5 bn €	Department manager	14
Electronics	above 2000	1–5 bn €	Team Member	7
Machinery	501–2000	1–5 bn €	Team leader	17
Logistics service provider	501–2000	100 m–1 bn €	Team Member	4
Logistics service provider	above 2000	above 5 bn €	General manager	13
Automotive	above 2000	1–5 bn €	Department manager	14
Automotive	above 2000	above 5 bn €	Team leader	9
Logistics service provider	above 2000	above 5 bn €	Team leader	7
Logistics service provider	251–500	100 m–1 bn €	Team leader	8
Logistics service provider	11–50	10–100 m €	General manager	8
Machinery	51–250	10–100 m €	Department manager	24
Electronics	above 2000	1–5 bn €	Team Member	6
Automotive	501–2000	100 m–1 bn €	Team leader	7
Logistics service provider	above 2000	above 5 bn €	Team Member	4
Automotive	above 2000	1–5 bn €	Department manager	24
Machinery	501–2000	1–5 bn €	General manager	21
Automotive	above 2000	above 5 bn €	Team leader	15

Applying the respective search string to each database identified 1,542 articles in Business Source Complete and 783 in SSCI. After eliminating 351 duplicates, a set of 1,974 articles was found. Subsequently, both researchers individually reviewed the titles and abstracts of all the articles and applied the inclusion criteria (see Table 2). As proposed by Durach (2016), interrater-reliability, here Cohen's Kappa (κ) (Cohen 1960), was calculated at 0.78, which indicates 'almost perfect' agreement (Richard and Koch 1977, 165). Thus, the authors determined a final set of 265 relevant articles that they then read, noting the application areas and antecedents that were either mentioned or recommended for further investigation, thereby creating to a list of 383 application areas and 221 antecedents of automation in LSCM (including duplicates).

Group exercise

In order to widen practical insights into this study, the authors conducted a group exercise that applied the NGT among 18 LSCM professionals (Table 4 outlines the sample demographics). It was intended to bring together a heterogenous group of practitioners from different industries with broad experience in LSCM to collect different views of this vital topic. The average professional experience of participants in LSCM was around 12 years. The participants of the group exercise met on-site to discuss the potential of automation in LSCM. The NGT is a structured, moderated group exercise methodology that, on the one hand, seeks to reduce bias in focus groups and, on the other hand, aims to enable on-site meetings and discussions, in contrast to Delphi techniques, which prohibit such interactions (Lloyd 2011; Green 1975). The NGT clearly separates the problem description from the problem solution (Delbecq and Van De Ven 1971) and has been proved to be efficient for LSCM research in extracting experts' knowledge in a structured way (Schoenherr et al. 2012; Nitsche and Durach 2018; Nitsche 2018). For applying the NGT, the group was subdivided into three sub-groups of six people, each group moderated by one researcher who ensured that the NGT process met the guidelines of Van De Ven and Delbecq (1971).

First, during the *problem description* phase, each participant individually had to think of possible application areas of automation in LSCM and write each of them on a single card. Subsequently, to exchange ideas within the sub-group, they applied a round-robin procedure in which one group member read out loud an application area that he/she had written down and explained it. Questions regarding the explanation of the application areas were allowed but the moderators controlled the discussions. This procedure enabled each group member to contribute equally. After collecting all application areas, the sub-groups summarised their results and explained them to the assembly.

Second, during the *problem solution* phase, each sub-group applied a procedure similar to the one applied in the first phase, first thinking of antecedents of successful automation projects in LSCM individually and then sharing the ideas within the groups through following the round-robin procedure. The NGT process led the practitioner groups to derive a set of 41 application areas and 53 antecedents (including duplicates).

Framework-building process

In order to propose a conceptual framework of automation in LSCM, it was necessary to further synthesise the automation applications and antecedents derived from the data triangulation provided by the SLR and the NGT exercise among LSCM professionals. Because the data triangulation led to the identification of 424 application areas of automation in LSCM (including duplicates) and 274 antecedents of successful automation projects (including duplicates), a structured approach was required to condense the application areas and antecedents in a more unbiased way. To achieve this, the authors applied the Q-methodology (Ellingsen, Størksen, and Stephens 2010), which other LSCM researchers have also used to synthesise categories through a structured bottom-up approach (cf. Nitsche and Durach 2018; Durach, Wieland, and Machuca 2015). The Q-methodology provides a structured approach in which a large set of attributes can be condensed to overarching meta-attributes. In the case of this study, it was a necessary step in order to synthesise the large set of attributes (application areas and antecedents) gathered from the data triangulation before providing the intended framework of application areas and antecedents of LSCM. The goal of the Q-methodology grouping process is to develop groups (meta-attributes) that are homogenous within each group of attributes but heterogenous among the groups. Two authors performed the framework-building process based on the Q-methodology, which was subdivided into three sub-steps: (1) synthesis of application areas, (2) synthesis of antecedents, and (3) development of the framework. In each sub-step, individual grouping processes were conducted.

Synthesis of application areas: First, each researcher individually performed a so-called Q-sort on the 424 application areas and applications derived from SLR and NGT. To do this, each researcher was provided with a set of all 424 automation applications written down on individual cards. Then, each researcher individually read those cards and built groups of cards that were, from a thematic point of view, homogenous within the groups but heterogenous among the groups. Therefore, each researcher read one card after another; opened a new group with the first card; read the second card; and assigned it to the existing group if there was thematic overlap or opened up a new group if there was no overlap. By applying this sorting procedure with all cards, each author derived an individual structuring of application areas. The authors then presented the sort results to one another and identified and discussed differences and similarities in the assignments. Following this discussion process, both authors jointly proposed a unified understanding of ten automation application areas in LSCM. Since some of the application areas identified included high numbers of cards/attributes (also indicating broad research in those application areas), the researchers decided to do individual Q-sorts within those application areas to further structure them. Consequently, for some of the application areas, additional sub-areas were built to provide further guidance for managers.

Synthesis of antecedents: Subsequently, the authors also individually applied the same sorting procedure to the set of 274 automation antecedents. After discussing the similarities and differences between both sorting results, the authors proposed a synthesised set of ten automation antecedents. During the discussion process, it had already become clear that the antecedents brought together have different traits and effects with respect to their impacts on the success of automation projects. The authors therefore decided to elaborate these commonalities and differences among the antecedents more clearly and to group the antecedents into further dimensions. Therefore, the researchers conducted another Q-sort, which was first developed individually and then discussed, leading to a common result. Based on this, the 10 antecedents were grouped into four mutually exclusive and collectively exhaustive dimensions.

Development of framework: The goal of this study was not only to identify application areas and antecedents, but also to understand how antecedents impact the efficient implementation and use of automation solutions im LSCM. Therefore, the researchers discussed possible amplifying, dampening, and moderating relationships between the antecedents and the efficient implementation and use of automation solutions in LSCM, thereby building on the underlying literature. By drawing on this discussion, an initial version of the framework was developed that was presented to an additional researcher who had not been involved in the research process so far. Building on the feedback, the final version of the framework was developed that proposes the direct influence of two dimensions of antecedents on the efficient implementation and use of automation solutions as well as two dimensions of antecedents that moderate this direct effect.

Review results

The aim of this study was to develop a conceptual framework that synthesises the application areas and antecedents of automation projects in LSCM to merge researchers' and practitioners' understandings on this vital topic. The framework developed (see Figure 2) comprises ten application areas and ten automation antecedents derived from an SLR and an NGT exercise

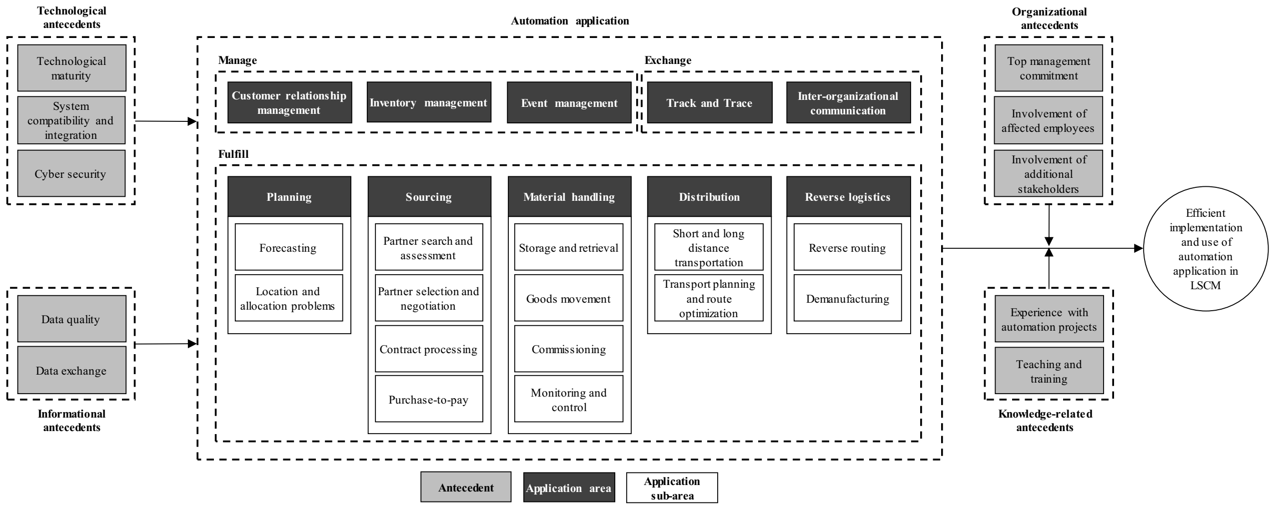

Figure 2. Conceptual framework of automation in logistics and supply chain management.

among 18 SCM professionals. We propose that the successful implementation of an automation application in LSCM is directly influenced by four *technological antecedents* (*technological maturity, cyber security* and *system compatibility and integration*) as well as two *informational antecedents* (*data clarity and intelligibility*, and *data exchange*). Although *technological* and *informational antecedents* can be considered as prerequisites for successful automation applications, additional antecedents further moderate this effect on successful automation implementation. More specifically, *organisational antecedents* (*top-management commitment, involvement of affected employees, involvement of additional stakeholders*) as well as *knowledge-related antecedents* (*experience with automation projects, teaching and training*) are proposed as moderators.

Application areas of automation in logistics and supply chain management

The rigorous data-gathering and structured synthesis process described above enabled the authors to condense the application areas of automation in LSCM. While the majority of the automation applications identified support the automation of the order fulfilment process (*planning, sourcing, material handling, distribution, reverse logistics*), several applications support either management functions (*inventory management, event management* or *customer relationship management*) or the exchange of information across the SC (*track and trace* or *inter-organisational communication*).

Application areas that are either extensively and diversely covered by the literature, or were discussed intensively within the group exercise, were further categorised into sub-areas. Figure 2 presents the structuring of those application areas and sub-areas. Although an in-depth discussion of research findings in all application areas is outside the scope of this study, we seek to provide assistance for the reader to orientate themselves in certain areas. Therefore, Table 5 provides an excerpt of research contributions, grouped by application area, for further reading. The numbers displayed beside the application area/sub-area express the number of cards from the q-sort that were assigned to this area, thus providing an indication of which areas the literature covers more extensively. (If an application area was mentioned or discussed in an article, it was written down on a single card.) As can be seen, *forecasting, partner selection and negotiation, transport planning and route optimisation* along with *storage and retrieval* are among the sub-areas of automation applications in LSCM most covered by the literature.

Antecedents of automation in logistics and supply chain management

The above data triangulation using an SLR and NGT exercise followed by the Q-methodology, enabled the authors to propose a synthesised set of 11 antecedents grouped into four different dimensions that influence the successful implementation of automation projects in LSCM. It can be observed that these antecedents impact the implementation of automation applications differently. While *technological* as well as *informational antecedents* directly impact the successful implementation of automation projects, it is the human factor that decides whether the project is a success due to contrasting perceptions, convictions, behaviours and knowledge across individuals who are endogenous or exogenous (e.g., SC partners) to the focal firm. Therefore, it is proposed that *organisational* as well as *knowledge-related antecedents* moderate the impacts that *technological* and *informational antecedents* have on the successful implementation of automation projects in LSCM. This is in line with recent advancements in LSCM research that highlight the importance of the

Table 5. Excerpt of research contributions regarding the application areas of automation in logistics and supply chain management.

SUB-AREA	AUTOR	MAIN CONTRIBUTION
PLANNING (73)		
Forecasting (64)	Küsters, McCullough, and Bell (2006)	Literature review on the current state of forecasting
	Kochak and Sharma (2015)	Demand forecasting using neural networks
	Nikolopoulos, Zied Babai, and Bozos (2016)	Demand forecasting for products with sporadic demand using a nearest neighbour approaches
	Carbonneau, Laframboise, and Vahidov (2008)	Comparison of advanced machine learning algorithms versus traditional forecasting methods based on incorrect database
	Villegas and Pedregal (2019)	Automated forecasting model selection for unobserved components
	Haberleitner, Meyr, and Taudes (2010)	Automated forecasting model selection using advanced order information
Location and allocation problems (7)	Gebennini, Gamberini, and Manzini (2009)	Development of a model to integrate strategic and tactical SC decisions on location and allocation problems
	Vargas Florez et al. (2015)	Development of a stochastic multi-scenarios program to support strategic humanitarian facility location problems
SOURCING (92)		
Partner search and assessment (17)	Mori et al. (2012)	Partner search through artificial intelligence-based match-making approach of firm profiles
	Choy (2002)	Partner search and assessment through automated detection and categorisation of collaborative suppliers
Partner selection and negotiation (41)	Chandrashekar et al. (2007)	Overview and comparison of automation approaches for negotiation process
	Brintrup (2010)	Utilisation of multi-agent technologies for automated coordination of sourcing and production processes
Contract processing (6)	Grosof and Poon (2004)	Utilisation of blockchain based smart contracts for automated contract processing
Purchase-to-pay (28)	Arrais-Castro et al. (2018)	Utilisation of multi-agent technologies to automate the purchase-to-pay process
MATERIAL HANDLING (86)		
Storage and retrieval (36)	Yu and De Koster (2009)	Development of a three-dimensional automated storage and retrieval system
	Marchet et al. (2013)	Development of a concept for an autonomous vehicle storage and retrieval system
	Bloss (2011)	Description of practice solutions for automated storage and retrieval system
Goods movement (22)	Bechtsis et al. (2017)	Development of a hierarchic framework for decisions regarding the use of automated guided vehicles in warehouses
	Bloss (2011)	Description of goods movement applications in practice
Commissioning (11)	Hou, Nathan, and Yu-Jen (2009)	Development of an algorithm to optimise picking planning using conveyor-aided systems
	Kim et al. (2002)	Utilisation of agent technologies to control commissioning processes
	Bloss (2011)	Description of commissioning solutions in practice
Monitoring and control (17)	Wen, Li, and Zhu (2018)	Utilisation of swarm robotics for decentralised control and execution of warehousing operations
	Higuera and Morenas (2014)	Utilisation of multi-agent system using RFID technology to support warehousing operations
DISTRIBUTION (50)		
Short and long-distance transportation (12)	Boysen, Schwerdfeger, and Weidinger (2018)	Description of an innovative solution for last mile delivery
	Fawcett and Waller (2014)	Discussion on the advantages of autonomous driving
Transport planning and route optimisation (38)	Alex (2002)	Development of a model for automated algorithm selection for route planning
	Bell and Griffis (2010)	Evaluation of route planning with the assistance of artificial intelligence
	García et al. (2013)	Development of a model to solve route planning problems
REVERSE LOGISTICS (11)		
Reverse Routing (6)	Barrera, Mario, and Cruz-Mejia (2014)	Development of an algorithm for reverse routing
De-manufacturing (5)	Williams (2007)	Literature analysis on computer-aided de-manufacturing
CUSTOMER RELATIONSHIP MANAGEMENT (6)		
Customer relationship management (6)	Cheung et al. (2006)	Development of a knowledge-based system to automate customer service for service logistics
	Abrahams et al. (2013)	Development of an algorithm to analyse blogs and social media for early detection of supply chain risks
INVENTORY MANAGEMENT (21)		
Inventory management (21)	Kang and Gershwin (2005)	Comparison of effectiveness of several technologies for inventory monitoring
	Kiil et al. (2018)	Comparison of impact of automated replenishment approaches in grocery stores on food waste
	Myers, Daugherty, and Autry (2000)	Comparison of effectiveness of several automatic inventory replenishment systems
EVENT MANAGEMENT (7)		
Event management (7)	Bearzotti, Salomone, and Chiotti (2012)	Development of an autonomous multi-agent approach to identify disruption risk and change plans dynamically
	Guarnaschelli, Chiotti, and Salomone (2013)	Development of an autonomous multi-agent approach to manage disruptive supply chain events
TRACK AND TRACE (31)		
Track and trace (31)	Navon and Berkovich (2005)	Development of system for automatic data collection along the supply chain to monitor material flows to improve materials management accordingly
	Bogataj, Bogataj, and Hudoklin (2017)	Development of a model for automated monitoring conditions for the transport of perishable goods and initiation of measures
INTERORGANISATIONAL COMMUNICATION (8)		

(*Continued*)

Table 5. (Continued).

SUB-AREA	AUTOR	MAIN CONTRIBUTION
PLANNING (73)		
Inter-organisational Communication (8)	Hill and Scudder (2002)	Investigation of impact of automatic electronic data interchange between supply chain partners in the food industry
	Agdas and Ellis (2010)	Design and implementation of an XML-based data exchange platform to reduce manual paper-based data exchange in the construction industry

human factor in LSCM (Schorsch, Wallenburg, and Wieland 2017).

Technological antecedents

The introduction of a new system for the automation of processes is associated with significant technological and financial risks. Monitoring and control of these aspects are crucial for automation. Hence, *technological antecedents* include all the factors that determine the technological suitability of an automation solution from a focal firm perspective in terms of maturity, security, and compatibility. More precisely, *technological maturity, cyber security* and *system compatibility and integration* are proposed as *technological antecedents*. Hence, we propose:

> *P_1: Technological antecedents directly influence the efficient implementation and use of automation applications since they have a direct impact on the resources expended for successful implementation.*

Technological maturity defines the degree to which a new technology is ready for successful implementation, adapted to the specific requirements of the context in which the focal firm is situated. The technologies and algorithms used to automate LSCM processes are highly complex. For comparatively new technologies, in particular technical problems, occur more frequently and are an essential factor in the development of these systems. Although the authors did not find an intensive discussion of this antecedent in the literature through the SLR, *technological maturity* was intensely discussed among the professionals in the NGT exercise. Practitioners unanimously agreed that they seek to use mature and ready-to-use systems that can provide value right away, since the use of an immature system poses a financial, an operational, or even a security risk.

System compatibility and integration ensures that a new technology is compatible with existing systems and guarantees simultaneous usability. Automation often means introducing a new system into a highly interdependent and complex system landscape of software and hardware components that interact with each other. To ensure full functionality, a new automation application must therefore be compatible with the systems and applications used within the focal firm as well as with the firm's interfaces to partners. Practitioners often identify this as one of the core challenges in introducing new technologies (Kersten et al. 2017). This is of particular relevance to applications within (but not restricted to) the application area of *material handling*, as warehouses are complex systems of numerous interdependent informational and physical systems that run in parallel. Therefore, when automating a sub-area of a warehouse, not only existing software systems, but also existing machines and their layout, must be included in a feasibility and compatibility assessment (Baker and Halim 2007; Mahroof 2019). The high importance of the compatibility of a new technology with the existing environment can lead to structural challenges in warehousing. Older structures, in particular, are often not appropriate for the use of new technologies. Practitioners should therefore consider adapting the existing layout as well as the processes used. In particular, the growing use of artificial intelligence in warehousing makes adjustments increasingly necessary (Mahroof 2019; Daugherty and James Wilson 2018).

Cyber security describes the ability to protect computer systems against theft or other attacks on hardware, software, data, or linked services. In an environment in which cloud computing and algorithms driven by big data are increasingly influencing corporate decision making and autonomous systems are gaining in importance, cyber-attacks present a growing risk that companies must address (Fawcett and Waller 2014). A non-negligible proportion of automation applications relies on cloud solutions that enable companies to analyse the huge datasets provided by 'big data' online before the results are stored locally. Particularly in such online systems, security gaps need to be closed to prevent external intervention and avoid data theft (Dalmarco and Barros 2018). However, this is not only relevant for online-based solutions. Future logistics systems aim to utilise automatically/autonomously guided vehicles not only in-house but also for short- and long-distance transportation, and this can be prone to data theft or manipulations that directly impact the success of those applications (Wen, Li, and Zhu 2018).

Informational antecedents

Regardless of the automation application, increasing amounts of data are required to automate physical as well as informational processes in LSCM. While some minor automation applications only require the internal data of the focal firm, more often external data is required, either from external providers or SC partners, to automate processes along the SC (Wu et al. 2016). Hence, *informational antecedents* include all the factors that enable timely access to correct and reliable data across the SC. More precisely, *data quality* and *data exchange* are proposed as two main antecedents within the *informational antecedents* dimension that directly impact on the efficient implementation and use of an automation application in LSCM. Hence, we propose:

> *P_2: Informational antecedents are prerequisites for system implementation and use and thereby directly influence successfulness of an automation project in LSCM.*

Data quality describes the degree to which data fulfils requirements affecting its efficient and target-oriented usability. If the usability of data is not ensured in a particular context, the success of an automation application is jeopardised. Because of its importance, data quality as an antecedent is intensely discussed in the literature, where the most commonly defined requirements for data quality are data access, clarity, reliability, and usability (cf. e.g. Pedroso and Nakano 2009; Jonsson and Gustavsson 2008; Mangina and Vlachos 2005). For an increasing number of applications, real-time availability of data is an additional requirement, e.g., for transport management (Bogataj, Bogataj, and Hudoklin 2017), warehouse operations (Wen, Li, and Zhu 2018), or autonomous driving (Cassetta et al. 2017).

Data exchange describes the level of sharing of knowledge or data between different persons or divisions within the focal firm and between the firm and its SC partners. This includes the technological capability (Ghadimi, Toosi, and Heavey 2018) as well as the willingness of partners along the chain to exchange data (Eurich, Oertel, and Boutellier 2010). The amount of information produced is increasing massively, thus opening up numerous possibilities for new automation projects. Nowadays, however, automation projects are rarely isolated solutions of individual companies or company divisions. The full potential of most technologies is only fully exploited when holistic concepts are implemented across several company divisions or across several SC partners (Wu et al. 2016). However, it has to be stated that, even within companies, data exchange can be challenging due to conflicting target systems and silo-thinking of divisions (Mahroof 2019). This is even exacerbated when it comes to trying to bring different companies, with different bargaining power across the SC, onto the same page (Eurich, Oertel, and Boutellier 2010), a view that the professional participants in the group exercise supported through their discussions.

Organizational antecedents

Automating LSCM-related processes within the focal firm or along the SC always involves humans with individual targets, beliefs, and concerns about this initiative. If they are not involved in the process of change from the start, either the implementation of the system will be delayed, or the implemented system will not be used as intended. *Organizational antecedents* describe the engagement of the humans, both endogenous and exogenous to the supply chain, involved in the implementation and use of the application. This is initiated by the top management of the focal firm and integrates employees who are directly affected by the automation initiative as well as additional stakeholders inside and outside the focal firm. Therefore, *top management commitment, involvement of affected employees* and *involvement of additional stakeholders* are proposed as *organisational antecedents*. Consequently, we propose:

> *P_3: Organizational antecedents moderate the impact of technological and informational antecedents since they ensure support from humans, endogenous and exogenous to the supply chain, involved in the application.*

Top management commitment describes the level of direct involvement and support of top management in implementation and use throughout the automation initiative. Automation projects are long-term projects that have far-reaching consequences for the processes within an organisation. Lack of support from decision makers is one of the key risks for projects that involve significant process changes (Wu et al. 2016). Case study research supports the importance of this antecedent regarding automation initiatives (e.g., Wang, Chen, and Xie 2010), as do questionnaires among multiple companies implementing automation applications (e.g., Baker and Halim 2007) and the NGT exercise.

Involvement of affected employees describes the level of consultation and consideration given throughout the project cycle to the needs and concerns of the staff affected by the automation initiative. Employees are often those most affected by the changes brought about by automation. The success of a project therefore depends on the participation and early involvement of the affected people (Mahroof 2019; Parasuraman, Sheridan, and Wickens 2000). The fear of an individual about losing their job or their expertise not being needed in the near future drives resistance to change. This fear is supported by recent studies that predict that 15% of jobs done by humans today will be automated by 2030, although that share could increase to 30%, depending on technological advancements (Manyika et al. 2017). Therefore, tackling these socio-technical challenges remains one of the core antecedents of automation projects (Fawcett and Waller 2014).

Involvement of additional stakeholders describes the level of consultation and consideration of the needs and concerns of other stakeholders affected by the project throughout the project cycle. These include both stakeholders endogenous to the SC, such as suppliers or customers, and stakeholders exogenous to the SC, such as politicians. More and more automation projects rely on data provided by SC partners to extend the picture observed. Hence, it is important to form strategic alliances with those partners, with benefits on both sides (Ghadimi, Toosi, and Heavey 2018). Autonomous driving is one of the most dominant applications discussed, where companies had to integrate governmental institutions in the early stages to mitigate the risk of being negatively affected by poorly-informed legislation (Fagnant and Kockelman 2015; Boysen, Schwerdfeger, and Weidinger 2018).

Knowledge-related antecedents

Developing, implementing, and using automation applications require technological as well as process knowledge. *Knowledge-related antecedents* describe the ability to adapt existing knowledge to new situations as well as to be able to obtain new knowledge that is necessary to ensure efficient implementation. Therefore, *experience with automation projects* and *teaching and training* are the two main antecedents in this field.

> *P_4: Knowledge-related antecedents moderate the impact of technological and informational antecedents since they ensure correct and efficient implementation and use of the application developed by the humans involved.*

Experience with automation projects describes the degree to which management as well as the project team have experience with similar projects and can adapt that experience to the new automation project. Recent studies have proven that companies with automation experience are much faster in implementing additional automation projects (Mahroof 2019). Companies with less experience should start by initiating smaller automation projects involving fewer stakeholders (Lord 2000). Professionals in the group exercise additionally expressed that either hiring experts in this field or acquiring external expertise for a limited time supports successful automation implementation.

Teaching and training describes the level of preparation of employees for dealing with the new technology, i.e., learning the necessary skills and behaviour patterns. Without the necessary knowledge, even the most advanced technological solution combined with high-quality data will not be implemented and used efficiently. Therefore, continuous *teaching and training*, adapted to technological change, can be understood as a moderator. Several studies have investigated the positive effects of *teaching and training* (Valverde and Saadé 2015; Baker and Halim 2007; Klumpp 2018) and the professionals support this.

Implications

The proposed framework of logistics and supply chain automation outlines ten automation areas as well as ten antecedents influencing the efficient implementation and use of automation applications in LSCM. It aims at synthesising current discussions in this field involving both research and practice by providing a coherent conceptualisation of automation in LSCM. The ten antecedents proposed are grouped into four dimensions: *technological, informational*, *organisational* and *knowledge-related antecedents*. While antecedents belonging to the first two dimensions directly impact the efficient implementation and use of automation applications, it is proposed that *organisational antecedents* (*top management commitment, involvement of affected employees* and *involvement of additional stakeholders*) and *knowledge-related antecedents* (*experience with automation projects* and *teaching and training*) moderate the impact of antecedents from the first two dimensions. The results provide further useful insights and implications for research and practice alike.

For research, the study provides a coherent, synthesised framework that outlines a conceptualisation of application areas and antecedents that can form a foundation for further research in this field. As Wu et al. (2016) stated, conceptual research on automation in the LSCM domain is sparse and we have aimed to contribute to this, as previous research has mostly focused on researching specific automation applications rather that contributing to an overarching understanding of the automation phenomenon. The results also stress the importance of the human factor in logistics and supply chain automation, which is an area of increasing importance in LSCM research in general (Schorsch, Wallenburg, and Wieland 2017; Wieland, Handfield, and Durach 2016).

The managerial contributions of this study are also diverse. First, an overview of possible application areas is provided, enabling practitioners to orientate themselves while being provided with further literature in a particular area. Second, the application areas provided by the framework can assist managers in assessing their current state of logistics and supply chain automation in a more structured way. This will enable them to assess the extent to which the automation projects they are currently implementing cover the broad spectrum of logistics processes, or whether they focus only on some partial aspects, leaving out other important areas. Third, the proposed framework supports practitioners in understanding the antecedents of successful automation applications and thereby carrying out automation projects in a more holistic way, considering all antecedents of automation projects right from the start. Although the individual configuration of those antecedents remains specific to the practitioner and the specific environment in which the automation application is situated, the proposed antecedents assist managers in setting up appropriate measures. The majority of LSCM managers from the group exercise reported that automation projects in their companies tend to focus more on the technical feasibility of the automation application, especially at the beginning, i.e., they tend to take care of the technological and informational antecedents (e.g., ensuring compatibility with existing systems, preparing and maintaining data quality, etc.) and only perhaps focus on the equally important but softer factors of such a project (e.g., the involvement of the employees who are about to use the automation solution) only in the later stages of the project. Often, affected employees are confronted with solutions that they are supposed to use but do not apply as hoped owing to the lack of their early involvement, and the lack of acceptance thus affects the overall success of the project. However, this study has shown that the organisational and knowledge-related antecedents moderate the effect of the technological and informational antecedents; thus, it becomes clear that these moderating factors are equally important and should be taken into account by practitioners at an early stage. The importance of the human factor in the introduction of technical solutions in a business environment, e.g., the introduction of ERP solutions (Somers and Nelson 2001; Karim, Somers, and Bhattacherjee 2007), is widely acknowledged in the literature and its relevance is also confirmed for automation projects. That being said, the study reminds practitioners that a mature automation application using the most recent and appropriate data can provide the intended value as long the moderating effect of the human factor, and more specifically the moderating effect of *organisational* as well as *knowledge-related antecedents*, is appropriately considered. In summary, it can therefore be stated that the study provides a guiding hand for managers who are seeking to implement automation applications.

Conclusion and final remarks

Through this study we have sought to provide a coherent picture of automation applications and the mechanisms driving the successful implementation and use of those applications in LSCM. Therefore, we performed data triangulation using SLR, including 265 articles, and an NGT exercise involving 18 LSCM professionals, to provide research and practice insights on this topic. More precisely, the proposed framework outlines ten application areas of automation in LSCM and further divides those into application sub-areas. Moreover, ten antecedents of efficient implementation and use of automation applications in LSCM were proposed and their effects were discussed. Those antecedents were structured into four dimensions of antecedents: *technological antecedents* (*technological maturity, system compatibility and integration, cyber security*); *informational antecedents* (*data quality, data exchange*); *organisation antecedents* (*top management commitment, involvement of affected employees, involvement of additional stakeholders*); and *knowledge-related antecedents* (*experience with automation projects, teaching and training*). It has been proposed that *technological antecedents* and *informational antecedents* have a direct effect on the efficient implementation and use of automation solutions, but the organisational antecedents and knowledge-related antecedents moderate this direct effect and are thus of equal importance.

This study therefore provides managers with a holistic view of the aspects to be considered in the development and implementation of automation solutions. Many of the antecedents described here have already been discussed in the LSCM literature in the context of other technology implementations (for example, involvement of affected employees, top management commitment, teaching and training; e.g., Somers and Nelson 2001; Karim, Somers, and Bhattacherjee 2007; Verhoeven and Nitsche 2020) and could also be confirmed in the context of automation projects in LSCM. However, this holistic view in the context of automation projects is new in form and thus extends the existing literature in the field. The managers involved in the group exercise of this research project also confirmed that a holistic view of the success factors or antecedents is often missing in automation projects and that the focus is mostly on the technical feasibility of the solution. In this respect, this study also contributes to the fact that managerial practice can usefully take a holistic, structured view of the antecedents when implementing automation projects.

Process automation is one of the core challenges for LSCM managers, and its importance is even increasing in the wake of the global COVID-19 pandemic (Straube and Nitsche 2020). The automation of individual processes is often the first step, or one of the early steps, that a company takes in the course of digitisation on the way to the autonomous, self-controlling logistics systems that, according to Junge et al. (2019), appear to be achievable in many companies by the end of this decade. Comprehensive autonomous systems require not only automated processes, but also intelligent, self-controlling and decision-making systems that must unite multiple actors and target systems. The approaches developed for cyber-physical logistics systems (Pujo and Ounnar 2018) offer promising structures for turning this vision into reality. Therefore, the automation of sub-processes in logistics networks represents a necessary step that companies are taking on the way to self-controlling cyber-physical logistics systems, even if both developments are not necessarily to be understood as successive steps but rather as parallel, complementary developments.

Nevertheless, no study is without limitations, which need to be pointed out. First, our results may be biased by the literature that we deemed appropriate to be included in the SLR. Nevertheless, by including multiple independent researchers in the preparation of the literature search as well as in the article selection, we aimed at reducing potential bias. Second, we restricted the literature search to peer-reviewed journals only, which is common practice but raises the shortcoming of excluding more practice-oriented literature. However, by also including 18 LSCM professionals and performing an NGT group exercise, we widened our study to include practical insights that may not have been found in the literature alone. Third, although the proposed antecedents and their effects on successful implementation and use were derived from a rigorous research procedure, they require further testing to draw more reliable results. Fourth, the proposed antecedents can be expected to impact automation implementation and use, but to different degrees depending on the specific application area. Unfortunately, the data gathered from the SLR and group exercise did not provide sufficient evidence that particular antecedents are more important for certain application areas than others, leaving the antecedent–application area relationship as a field for future research.

This directly leads us to our call for future research on logistics and supply chain automation. The present study is qualitative in nature and is the first of its kind that has aimed at synthesising the application areas and antecedents of automation in LSCM. Further quantitative research is necessary to verify the existence of the proposed effects as well as to draw more reliable conclusions.

Acknowledgments

The authors would like to thank the Kuehne Foundation for the financial support of this study.

Disclosure of potential conflicts of interest

No potential conflict of interest was reported by the author(s).

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