Exploring the application areas and antecedents of automation in logistics and supply chain management: a conceptual framework

Benjamin Nitsche * [1], Frank Straube [2], Maximilian Wirth [2]

[1] Berlin University of Technology – Straße des 17. Juni 135 10623 Berlin, Germany
[2] Berlin University of Technology – Germany

Purpose: To remain competitive, companies nowadays need to find ways to reduce costs and increase the efficiency of their operations. To achieve this, one of the main challenges for modern logistics and supply chain management (LSCM) is the automation of informational and physical processes along the supply chain. Although research on different automation applications in LSCM exists (e.g., in purchasing, inhouse operations, and distribution processes), LSCM managers lack an overall picture of possible application areas as well as the antecedents influencing the successful implementation and use of automation applications in LSCM.
Research Design: This study applied data triangulation through a systematic literature review of 265 articles and a Nominal Group Technique (NGT) exercise among 18 LSCM professionals. Subsequently, a structured synthesis process was applied. This built on the Q-methodology to propose a framework that outlines the application areas and antecedents of automation in LSCM.

Results: The research process combines insights from research and practice to propose a framework that synthesizes 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 *organizational* as well as *knowledge-related antecedents*, and advances propositions outlining the impact of antecedents on the successful implementation and use of automation applications.

Theoretical contribution: The study provides a coherent conceptualization of automation in LSCM, thereby synthesizing widespread knowledge on this vital topic. For LSCM research, in particular, it provides a common basis on which to merge further discussions on automation. To the best of our knowledge, there has been no systematic previous approach conceptualizing automation in LSCM by application areas and the antecedents impacting on them.

Managerial contribution: The topic of automation is of utmost importance for LSCM managers and the results of the study support those managers' orientation toward and positioning in this field. By obtaining insights into the application areas of automation, this study provides managers with the current state of research and will enable them to draw conclusions for practice from it. The conceptualization of the antecedents of efficient automation implementation and use can support managers in purposefully implementing projects related to the topic.

*Speaker

Limitations: The article extends knowledge on automation in LSCM for research and practice by providing a coherent conceptualization. However, the framework, especially the antecedents of automation, require further quantitative testing in order to draw more reliable conclusions.

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1. INTRODUCTION

In an era of digitalization, 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 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 emphasized 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). Mooney et al. (1996) categorize 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 et al. (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, 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 the efficient implementation and use of automation projects in LSCM?

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 control time and cost under control, and having it utilized 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.

2. 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 industrialization and digitalization, the aspect of supporting tasks that humans alone cannot solve 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.*

Table 1 – Understandings and definitions of automation

Authors	**Definition/understanding of automation**
Bainbridge (1983, p. 775)	"The classic aim of automation is to replace human manual control, planning and problem solving by automatic devices and computers."
Sheridan (1992, p. 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."

Raja 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."
Raja 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."

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).

3. RESEARCH DESIGN

In order to outline the application areas of automation in LSCM and to synthesize 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 synthesize 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 synthesizes the application areas and antecedents of automation in LSCM from the perspectives of research and practice. Figure 1 outlines the overall research procedure.

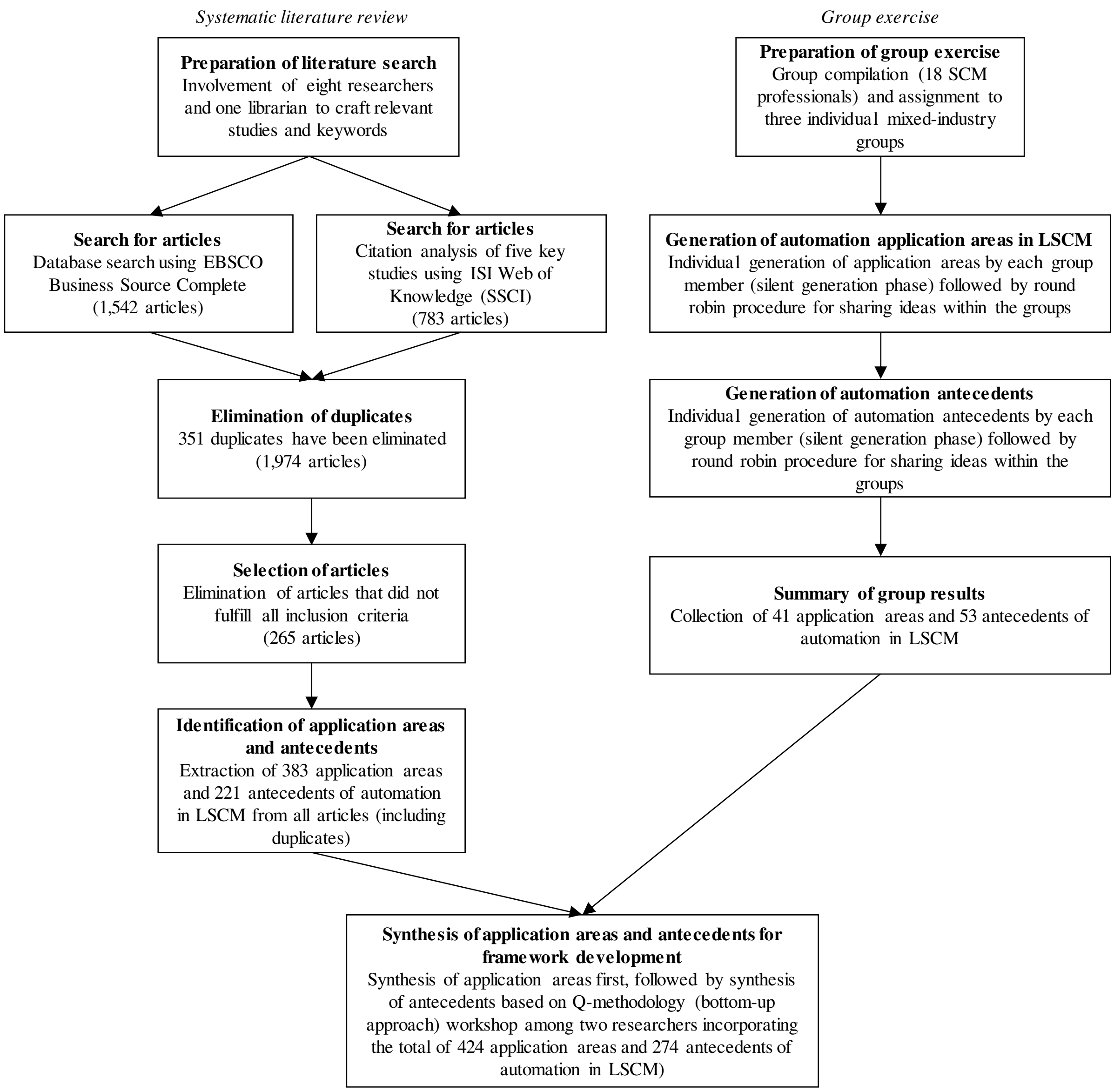

Figure 1 - Research procedure

3.1. Systematic literature review

Conducted rigorously, SLRs in LSCM research can assist in synthesizing widespread knowledge in order to advance current research in a field (Christian F. Durach 2016; Christian F. Durach, Kembro, and Wieland 2017). 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).

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

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 identifying literature dealing with the application areas and antecedents of automation in LSCM and to propose a search string combining these keywords. Both 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.	

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 (Landis and Koch 1977, p. 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).

3.2. 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 summarized their results and explained them to the assembly.

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	100m - 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	100m - 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	100m - 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

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).

3.3. Framework-building process

In order to propose a conceptual framework of automation in LSCM, it was necessary to further synthesize the automation applications and antecedents derived from the data triangulation provided by the SLR and the NGT exercise among LSCM professionals. To achieve this, the authors applied the Q-methodology (Ellingsen, Størksen, and Stephens 2010), which other LSCM researchers have also used to synthesize categories through a structured bottom-up approach (cf. Nitsche and Durach 2018; Durach, Wieland, and Machuca 2015). First, each author individually performed a Q-sort on the 424 application areas and applications derived from SLR and NGT. Each researcher was provided with a set of all the automation applications written down on 424 individual cards. Each 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. 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. Application areas that the literature discusses intensely were further sorted into sub-areas.

Subsequently, the authors also applied the sorting procedure to the set of 274 automation antecedents. After discussing the similarities and differences between both sorting results, the authors proposed a synthesized set of ten automation antecedents, further categorized into three dimensions. Building on the results of both Q-sorts, the authors developed a conceptual framework that outlines the application areas and the antecedents of automation in LSCM.

4. REVIEW RESULTS

The aim of this study was to develop a conceptual framework that synthesizes 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 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, *organizational 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.

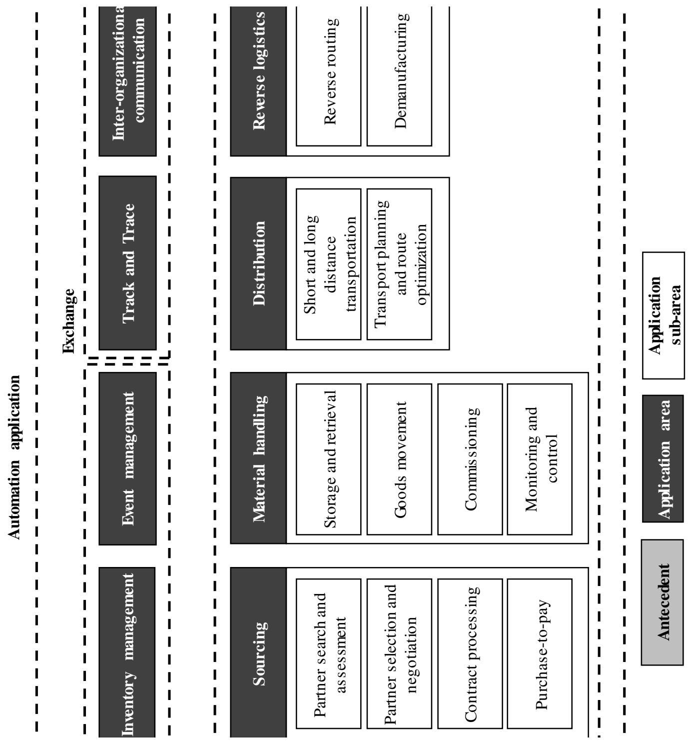

Figure 2 - Conceptual framework of automation in logistics and supply chain management

4.1. 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 fulfillment 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-organizational communication*).

Application areas that are either extensively and diversely covered by the literature, or were discussed intensively within the group exercise, were further categorized 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 optimization* along with *storage and retrieval* are among the sub-areas of automation applications in LSCM most covered by the literature.

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, Babai, and Bozos (2016)	Demand forecasting for products with sporadic demand using a nearest neighbor 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 categorization of collaborative suppliers
Partner selection and negotiation (41)	Chandrashekar et al. (2007)	Overview and comparison of automation approaches for negotiation process
	Brintrup (2010)	Utilization of multi-agent technologies for automated coordination of sourcing and production processes
Contract processing (6)	Grosof and Poon (2004)	Utilization of blockchain based smart contracts for automated contract processing
Purchase-to-pay (28)	Arrais-Castro et al. (2018)	Utilization 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, Wu, and Wu (2009)	Development of an algorithm to optimize picking planning using conveyor-aided systems
	Kim et al. (2002)	Utilization of agent technologies to control commissioning processes
	Bloss (2011)	Description of commissioning solutions in practice
Monitoring and control (17)	Wen, He, and Zhu (2018)	Utilization of swarm robotics for decentralized control and execution of warehousing operations
	Higuera and de las Morenas (2014)	Utilization 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 optimization (38)	Van Breedam (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)	Manuel Monsreal Barrera 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 analyze 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
INTERORGANIZATIONAL COMMUNICATION (8)		
Inter-organizational 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

4.2. 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 synthesized 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, behaviors and knowledge across individuals who are endogenous or exogenous (e.g., SC partners) to the focal firm. Therefore, it is proposed that *organizational* 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 human factor in LSCM (Schorsch, Wallenburg, and Wieland 2017).

4.2.1. 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*, since 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 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 analyze 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 utilize 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, He, and Zhu 2018).

4.2.2. 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 jeopardized. 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, He, 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, Ghassemi 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.

4.2.3. 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 *organizational 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 organization. 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 per cent of jobs done by humans today will be automated by 2030, although that share could increase to 30 per cent, 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, Ghassemi 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).

4.2.4. Knowledge-related antecedents

Developing, implementing and using automation applications requires 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 behavior 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.

5. 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 synthesizing current discussions in this field involving both research and practice by providing a coherent conceptualization of automation in LSCM. The ten antecedents proposed are grouped into four dimensions: *technological*, *informational*, *organizational* 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 *organizational 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, synthesized framework that outlines a conceptualization 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).

For practice, the study provides a guiding hand when seeking to implement automation applications. 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 proposed framework supports practitioners in understanding the antecedents of successful automation applications. Although the individual configuration of those antecedents remains specific to the practitioner and the specific environment that the automation application is situated in, the proposed antecedents assist practitioners in setting up appropriate measures. The study also reminds practice 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, more specifically the moderating effect of *organizational* as well as *knowledge-related antecedents*, is appropriately considered.

6. 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. 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 synthesizing 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.

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