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Toward an automated supply chain: technological overview and evaluation of readiness

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Abstract

The increasing complexity, cost, and uncertainty of modern supply chains have boosted growing interest on the concept of supply chain automation (SCA). Scope of SCA in nowadays scenario is broad, moving from the idea of physical automation to the one of digital automation of information and business processes, that will be the focus of this thesis. Given the broad range of processes and of technologies enabling their automation, clarifying the concept of "supply chain automation" is valuable. It has indeed received few attentions from academicians, that have to some extends overlooked SCA implementation complexity form a technological and managerial perspective. This thesis aims to fill this gap, and to assess the current technological readiness toward the creation of a completely automated SC. The key technologies identified include Robotic Process Automation (RPA), mainly relevant for tasks execution and transactions automation, Internet of things (IoT) and Cloud computing for automation of data collection, transfer and monitoring, Artificial intelligence (AI) and big data analytics (BDA) for decision-making automation, with focus on recommendations systems, predictions, and planning automation, and Blockchain, for automation of secure transactions through smart contracts. In addition, cyber physical systems (CPS) and supply chain digital twin (SCDTs) technologies have been showing superior performance to achieve orchestrated automation which impact entire stages of the supply chain or even the whole network. The research highlights the fact that the journey toward a completely automated SC is still long, given key challenges of technological integration, organizational readiness, and lack of skills. Managerial insights suggest the relevance of developing a clear strategy and common mindset toward automation before any practical implementation and to implement IoT and Cloud technologies fast in the SCA journey, to provide the required visibility for later development of AI-based decision-making automation. Integration of AI, IoT, and Cloud is relevant for orchestrated automation.

Keywords: Supply chain automation (SCA), business process automation, information automation, technological readiness, implementation roadmap, automated supply chain.

Abstract in italiano

La crescente complessità, i costi e l'incertezza caratterizzante le moderne supply chains hanno stimolato un maggiore interesse verso la loro automazione. Questo concetto può assumere diversi aspetti, da automazione fisica a digitale: quest'ultima sarà analizzata in questa tesi, con focus su automazione delle informazioni e dei processi aziendali. Data l'ampia gamma di processi e di tecnologie che ne consentono l'automazione, è utile presentare una chiara definizione del concetto di "automazione della supply chain", di cui è spesso stata trascurata la complessità tecnologica e manageriale della sua implementazione. Questa tesi mira a colmare questa lacuna e a valutare l'attuale preparazione tecnologica verso la creazione di una supply chain completamente automatizzata. Le tecnologie chiave identificate includono Robotic Process Automation (RPA), rilevante per automazione di attività e transazioni, Internet of Things (IoT) e cloud computing per automazione della raccolta, trasmissione e del monitoraggio dei dati, Intelligenza artificiale (AI) e Big Data Analytics (BDA) per l'automazione del processo decisionale, con particolare attenzione ai sistemi di raccomandazioni, previsioni e automazione della pianificazione, e Blockchain, per l'automazione delle transazioni in sicurezza. Inoltre, le tecnologie di cyber physical systems (CPS) e del digital twin (SCDT) hanno mostrato prestazioni superiori nell'ottica di un'automazione orchestrata che incida su intere fasi della SC o addirittura sull'intera filiera. La ricerca evidenzia il fatto che l'obbiettivo di una supply chain completamente automatizzata è ancora lontano, viste le sfide legate a integrazione tra tecnologie e sistemi, e mancanza di competenze. Gli spunti manageriali suggeriscono l'importanza di sviluppare una strategia chiara e una mentalità comune verso l'automazione prima di qualsiasi implementazione, e di introdurre rapidamente le tecnologie IoT e Cloud, per fornire la visibilità necessaria all'AI. L'integrazione di AI, IoT e Cloud è rilevante per raggiungere un'automazione orchestrata.

Parole chiave: automazione della supply chain, automazione dei processi aziendali, automazione delle informazioni, preparazione tecnologica, percorso di implementazione, supply chain automatizzata.

Contents

1 Extended abstract

1.1. Introduction

Supply chains are becoming more complex, costly, and uncertain. At the same time technology and information advancements open a high number of new possibilities: one of the key elements of this digital transformation is the concept of supply chain automation (SCA). Scope of SCA in nowadays scenario is broad, moving from the initial concept of physical automation in the manufacturing context to the one of digital automation of information and business process, that will be the focus of this thesis. This concept involves the use of technologies and software to automate the management of information flow and business processes, to optimize data- and information- related tasks and their orchestration.

RPA is the most widespread technology, with 78% of companies already implementing it, and 16% planning to do it in the next three years, according to Watson et. Al. survey [1]. However, it is also clear that limiting supply chain automation to RPA is not sufficient anymore: possibilities opened by implementation and integration of other technologies needs to be exploited. Different technologies have different impacts on automation and therefore on how they re-shape management of supply chains. Moreover, automation potential does not lie in a single technology but rather in an ever-increasing range of technologies, tools and techniques that need to work in concert with one another. In this context, the idea of building an automated supply chain, able to perform the entire end-to-end flow, from procurement to production, inventory, transportation, delivery, and demand management, is receiving more and more attention. Data, decision-making and execution would be completely automated in an integrated way across all stages, leading to optimization of the entire supply chain eco-system. However, such configuration is linked with not few challenges and barriers, starting from lack of technological and IT infrastructures and skills, going to high costs and high complexity of implementation and management.

Given the complexity of SCA from a technological perspective, as well as in terms of heterogeneity of processes automatable, the need of a more comprehensive analysis of the concept is needed, with focus on its technological readiness for integration toward an automated SC.

1.2. Methodology

To carry out the analysis a systematic literature review was performed on the Scopus database. The query was structured as follow:

TITLE-ABS-KEY ("supply chain" AND "process automation")

The research returned 137 papers that were screened through filters related to publication year, subject area, document type, availability, and alignment with research scope. Through snowballing other eighteen papers were included, and additional 10 were found in the grey literature, published from leading vendors of supply chain business process automation solutions or consultancy companies active in the field. The total amount of 52 papers was analysed in detail, and results are described in the following paragraphs.

1.3. Research objective

If it is true that the concept of automation applied to business processes and information in the supply chain is being widely studied and discussed by academicians, it is also true that a lack of a comprehensive overview about "supply chain automation" is missing. Only 2 out of 52 articles reported a specific definition of it and seven papers expressed the need for future research in this direction. Supply chain automation indeed, has been receiving more attention from practitioners and vendors rather than by researchers. As a result, the academic community has, to some extent, overlooked the complexities and heterogeneity of options of real-world applications, in terms of different business processes, technologies, and different level of complexity and integration. Given the current situation, it may be hard for companies to identify the best way to pursue supply chain automation on the base of their needs.

This thesis aims to fill this gap focusing on identifying the different roles of technologies enabling SCA, and their readiness for an orchestrated integration in the direction of building an automated supply chain. Managerial implications are also analysed, to help companies identify the best roadmap to approach SCA.

For this purpose, the following research questions are analysed:

- RQ1 – Which are the key technologies available for supply chain automation?
- RQ2 - How can supply chain automation be operationalized?
    - RQ2.1. - Which technologies are more suited for automation of which business processes?

    - RQ2.2. – What is the technological readiness of supply chain automation in the direction of building an automated supply chain?
- RQ3 – Which are managerial implications of supply chain automation?

1.4. Supply chain automation

Supply chain automation has been defined as: "The partial or full replacement 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. It involves integrating disruptive digital and operations technologies that reduce the dependencies of SC operations on human interventions."

Automation typically comes into the equation of supply chains for two interrelated reasons: improve people productivity, referred by [2] as the primary driver of SCA effort, and reduce operational costs. Other relevant benefit is increase in resilience to complexity and disruption, given by the higher visibility, responsiveness, proactivity, and intelligent support in decision making enabled by SCA, especially in relevant in modern and global environment. In addition, enhancement of processes compliance due to error elimination, and improve in customer experience are registered. Nevertheless, SCA presents several challenges: lack of IT readiness and skills, integration problems among technologies and systems, availability and quality of data, lack of a clear vision and a common mindset toward automation in line with the company strategy, employee resistance to change and high costs, are the most relevant ones.

1.5. Technologies and their potential for SCA

Adoption of technologies for automation of the supply chain represents a shift in how value is created. The key ones identified and their major role in SCA are the following:

Robotic Process Automation

Robotic Process Automation (RPA) can be defined as "a preconfigured and programmed software robot that automate repetitive manual tasks emulating human workers and their interactions with digital systems. It uses business rules and predefined activity choreography to automate the execution of a combination of business processes, activities, transactions, and tasks in one or more unrelated software systems to deliver a result or service with human exception management".

RPA finds perfect application in the automation of tasks executions and transactions. In general, process suitable for RPA automation are "routine tasks": repetitive and rule-based, with high volume of predictable transactions, with very limited exception handling and mature. Typical applications include automation of data entry, transfers and extraction from documents and ERP systems, simple calculations, and form completion. RPA shows clear benefits in terms of productivity increase, processing time reduction and compliance, and quality levels improvements.

Advanced analytics

Artificial Intelligence (AI) and Big Data Analytics (BDA) technologies are analysed under this category. AI can be defined as a "Technology that has a system's ability to correctly interpret data, understand relationships, learn from such data, and use those learning to achieve specific goals and tasks through flexible adaptation, providing visibility into operations, and support better decision making.". In the scope of SCA, great attention is put toward Machine learning, an AI subset. Big data is a "technology that treats ways to analyse and systematically extract information from large data sets". In the scope of SCA, their role and potential has been analysed jointly.

They are necessary when cognitive capabilities and human-like intelligence is required, given their ability to process unstructured data, recognize patterns and categories, and deal with high volume of complex inputs for logical reasoning and problem-solving. Indeed, they find perfect applications in the automation of planning and its optimizations, and predictions, such as demand forecasts and predictive maintenance. Automated recommendations systems, to identify best way to answers to problems or changes detected in the supply chain, is another relevant field of AI application.

Cloud computing

"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction".

Cloud computing represents one of the keys enabling technologies of automation, thanks to the achievable real time availability, visibility and integration of data and resources on the internet rather than on local infrastructure, often implemented through Cloud-based ERP systems. Data monitoring automation is enabled, such as shipment track and trace, thanks to integration with IoT for data collection and with AI for active monitoring of changes and problems on data, improving SC reactivity and reducing uncertainty and risks.

Internet of Things

Internet of Things (IoT) can be defined as: "physical devices that collect data, a network that transmits the collected data, and an application layer which includes IoT applications and services, to realize searching, identification, location, tracking, monitoring and management on the internet."

IoT introduction reflect the necessities to automate data capturing: it is able to collect and communicate data in real time, improving information accuracy and data integration. This enhances end-to-end transparency and visibility, especially considering that, at present, majority of IoT applications are developed in the Cloud. Data collection and monitoring automation enabled by these technologies provide the necessary database for more complex automation based on data analysis and decision-making.

Blockchain

Blockchain can be defined as a: "Distributed, decentralized, digital ledgers sequentially linked using cryptography and supported by a network of multiple computers".

Greater contribution of blockchain in SCA is the automation of routine transactions through smart contracts, that can be defined as "a computerized transaction protocol that executes the terms of a contract". They automate execution of contract clauses and payment release, making them secure, transparent, and reliable. They enable peers in the network to have full access and visibility to the history of all the smart contracts and transactions, as well as their current state. Trust among partners increases, and collaboration is enhanced.

Supply chain digital twins

Supply Chain Digital Twins (SCDTs) definition can be formulated as: "A dynamic simulation model which features a long-term, bidirectional, and timely datalink to the real supply chain system. It aggregates the available data in a structured way and allows simulations on the supply chain's performance, identifying where volatility and uncertainty exist, as well as where optimization is possible. It also enables scenario planning so that a company can make decisions based on business needs.". SCDTs technology is represented by the model, the environment, and the engine of the simulation. Several synergistic technologies must be involved, namely IoT, 5G, Cloud, and AI-based algorithms.

SCDTs can capture data and use them to model simulation of the whole network, allowing full system monitoring, control, visibility, and transparency, as well as problems detections, such as presence of bottlenecks in production or achievement of a certain stock level in warehouses. Identification on how best react to them is also automated. Trough simulations, it is possible to identify where volatility and uncertainty exist, as well as where optimization is possible, enabling risk prediction and mitigation, decision making and planning in an orchestrated way. Digital twins offer a completely new way for planning supply chains: thanks to its possibility to simulate and evaluate opportunities on a digital platform that enables scenario planning on the base of the business needs.

Cyber Physical Systems

"CPS are systems of interconnected physical and computational objects, resulting in a close coupling of the cyber and physical contexts: assets and resources of the supply chain are integrated with computational components and can be monitored and controlled through computer-based algorithms". In this connected system, sensors, machines, workpieces, and IT systems are linked along the value chain beyond a single organization. CPS includes technologies for sensing and actuating, first Internet of things, coupled with wireless communication technologies, robotics and AI-based computational power. Even digital twins can be integrated as a part of a CPS.

CPS allow the increasing integration of information and decision capabilities into industrial production and introduce new potentials for the planning, control, and the organization of as supply chains. They are indeed able to automate data capture, monitoring, problems detections, up to decision making and execution.

1.6. Toward an automated SC

SCA can go beyond single and specific processes automation and embed the orchestration of several integrated ones. This enlarges the automation scope and potential, as well as its impact on the supply chain. Final goal in this direction is the creation of an automated supply chain where the entire end-to-end flow, from procurement, production, transportation and logistics, inventory, delivery and demand management is automated and data, decisions and execution are integrated and synchronized across all stages and actors.

Majority of automation initiatives described were found to be partial, with manual intervention needed for some decision making and execution steps. In addition, impact of the described automation was mainly on a local level rather than on entire stages, or on the whole network. At stage level, major attention is put toward procurement and production management automation. For the former, a completely automated solution was not identified, and [16] underlies how automation of all the functions in the procurement process is still not achievable with single systems or applications. For the latter a more complete and comprehensive automation can be reached thanks to CPS. The only automation reported that extends its impact across multiple stages and functions is described by [3], through employment of SCDTs. Even given its potential for reaching automation and integration of functions on an orchestrated network level, it still requires human intervention for some decision making and implementation. SCDTs integration in CPS could be an interesting configuration to enlarge automation potential, even if linked with high costs and complexity.

Results highlight the fact that the journey toward building an automated supply chain is still long and that technology readiness is not sufficient yet. Barriers for the implementation of these integrated automation are mainly integration problems among technologies and systems that needs to work together, and organizational readiness: lack of a clear strategy and roadmap for implementation, as well as leadership support to manage the change. Other relevant challenges in this direction are lack of IT readiness, skills, and knowledge to implement, manage and exploit technologies for automation, in addition to barriers of data requirements.

1.7. Managerial implications and implementation roadmap

Given the complexity and heterogeneity of SCA and its technologies, several managerial insights may be relevant for companies to be analysed, to assess the best way to approach automation.

Development of a common strategic mindset toward automation and a clear direction to follow, shared across the organization, is a needed pre-requisite for SCA success.

IoT and Cloud implementation are a good first step toward SCA, for automating data collection and monitoring. Data quality and completeness would enhance SC visibility and its performance on a global scale, and put the basis for development of AI-based algorithms. IoT implementation is related to significant costs, given the broad volume and range of sensors to implement: its introduction in SC can start from more relevant processes, and gradually expand. In addition, RPA-based tasks execution automation appears a good starting point, to improve productivity, standardize processes and improve data quality and compliance. Barriers for its implementation and related costs are not too challenging, and benefits clearly measurables.

AI being the most discussed, as well as the most challenging technology for SCA, is relevant to be implemented for providing active monitoring and recommendation, prediction, and planning automation. Introduction for automation require IT readiness, skilled workforce, and data requirements, achievable through integration with the Cloud- database. Its implementation could start from "easier" algorithms to start accustoms the necessary skills and knowledge to manage it, and then expand to more complex ones.

AI, IoT and Cloud are the most present technologies in complex and integrated automation initiatives, and also key components of both CPS and SCDTs, that could represent a last step in SCA, given their technological complexity, which is mainly based on all above-mentioned technologies.

Blockchain should be considered for SCA only when strict requirements in terms of products traceability and authenticity, and transaction security, are relevant. In these situations, transactions automation through smart contracts provides great benefits. In other cases, complexity of implementation does not justify its introduction, also because its role is not significant in reaching more complex and integrated forms of SCA.

1.8. Conclusions

Supply chain automation clearer definition and understanding of its benefits and implementation challenges is carried out in the thesis, with focus on enabling technologies and their roles given the wide range of SC business processes. Technological readiness toward the creation of a completely automated SC is assessed and managerial insights for companies moving in the direction of SCA are provided, for smooth implementation. These contributions are aimed to fill the literature gap linked with the diversified and fragmented vision about SCA.

2 Introduction

Supply chains are becoming more complex, costly, and uncertain. At the same time technology and information advancements open a high number of new possibilities in the scope of digital transformation of the supply chain. These not only allow to overcome current challenges but to release new potentials to enhance supply chain performances and completely redesign the way supply chains are managed and run. One of the key elements of this digital transformation is the concept of supply chain automation.

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. It involves integrating disruptive digital and operations technologies that reduce the dependencies of SC operations on human interventions" [4] [5]. By connecting machines, assets and IT systems via software, a cohesive intelligent network is created, data is produced, and insights is obtained. This can be exploited and architected to automate the delivery of key information and physical product through the end-to-end supply chains [6].

2.1. Motivation and problem statement

Scope of automation in nowadays scenario is broad, moving from the initial concept of automation in the manufacturing context to the one of digital automation. Indeed, current automation efforts also target work that is related to the interaction between humans, resources, and computers [7], the so-called information automation, or business process automation. This concept involves the use of technologies and software to automate the management of information flow of business processes, to optimize data- and information- related tasks and their orchestration This type of automation is the one on which this thesis focuses, rather than the physical one.

Different initiatives for process automation in the context of supply chain management differentiate themselves on the base of which process undergo automation journey and which technologies are used to reach the desired level of automation. The most common technologies for the scope are robotic process automation (RPA), artificial intelligence (AI), advanced analytics of big data (BDA), cloud computing, Internet of

Things (IoT), blockchain, digital twins (SCDTs) and cyber physical systems (CPS). RPA is the most widespread technology, with 78% of companies already implementing it, and 16% planning to do it in the next three years, according to Watson et. Al. survey [1]. RPA is indeed often companies' first step toward automation [8], due to its ability to automate "routine tasks", which are abundant in supply chain management, and its (relatively) easy, fast, and cheap implementation process. However, nowadays it is also clear that limiting supply chain automation to RPA is not sufficient anymore: possibilities opened by implementation and integration of other technologies needs to be exploited. Different technologies have different impacts on automation and therefore how they re-shape management of supply chain. Moreover, automation potential does not lie in a single technology but rather in an ever-increasing range of technologies, tools and techniques that need to work in concert with one another. Integration of different technologies can lead to more complex and integrated automation, embedding and orchestrating the execution of several processes and functions.

In this context, the idea of building an automated supply chain, able to perform the entire end-to-end flow, from procurement to production, inventory, transportation, delivery, and demand management, is receiving more and more attention. Data, decision-making and execution would be completely automated in an integrated way across all stages, leading to optimization of the entire supply chain eco-system. However, such configuration is linked with not few challenges and barriers, starting from lack of technological and IT infrastructures and skills, going to high costs and high complexity of implementation and management. The current level of advancement and maturity of supply chains and technologies towards a complete automated configuration is a matter of deep interests, together with identification of best managerial practices and most suitable roadmap for moving toward this direction.

This knowledge may be hard to be reached by companies, given the broad ranges of options available for implementation of supply chain automation.

2.1.1. Need for supply chain automation

Automation is a concept that cannot be ignored in nowadays management of supply chains. Reasons behind this lie in two main evolving elements: the increasing complexity to manage when dealing with supply chains, and the technology and information advancements, that open doors to new ways to overcome these challenges and to enhance performances.

Supply chains are becoming substantially more challenging to manage. The trend of globalization and internationalization of operations lead to a shift of both customers and suppliers' base, as well as company's assets, that are nowadays often based in different parts of the world. Complexity arising in supply chain management from this globalization trend takes several forms [9]:

- Longer lead times. Interlinked physical flows are becoming longer, with consequent increase in uncertainty. In addition, planning becomes harder since it requires longer-term horizons and relies on a less accurate forecast accuracy.
- Formal relationships. Managers and partners of the supply chain do not work in close contact with each other, and this change and reshape the way relationships are build and that trust is created, especially after Covid-19 pandemic. In addition, the number of partners increase. Direct impact of this is not only the increased difficulty in building trust, but also higher fragmentation of data sources, formats, and systems within the whole network. Information incompleteness and ambiguity has increased [10].
- Increase of capital tied up in inventory. Due to longer lead times, stocks, particularly in transit ones, become an important cost item to manage, that requires higher financial needs. Increase in planning complexity also translates in non-optimal inventory levels and position within the network, source of additional costs.

Customer requirements are also changing. Customers nowadays expect to have everything at every time, everywhere. The so called "Amazon effect" place new challenges to supply networks that are required to be fast, flexible, and able to dynamically adapt to customer needs. Customers' purchasing behaviours was also impacted by the Covid-19 pandemic, that lead to an increase of demand fluctuation [10].

All these elements increase the uncertainty and risk of supply chains management and therefore the attention towards the necessity of building a resilient supply chain, based on visibility, flexibility, responsiveness, and trust. The strength of resilience is not to be able to adapt to a specific change, but to all possible, unpredictable events that can impact the supply chain. Recent historical events, first Covid-19 pandemics, emphasised the importance of resilience capabilities building in supply chain networks to ensure survival. Being able to anticipate, understand, and react to unpredictable sources of changes is now a primary focus of all companies.

Ghobakhloo et. al. identifies in supply chain automation the most critical component for pursuing supply chain resilience, stating that it should be the first area to be addressed in the path of digitalization of the supply chain [5]. Supply chain automation, thanks to increased data quality and integration, connectivity, visibility, transparency, processes compliance, and intelligent support in planning and decision making, can helps supply chain in reaching this scope [11]. Supply chain can be able to timely detect problems and react to them in the optimal way, as well as to forecast future uncertainty and prepare to it. But supply chain automation is not only a fundamental enabler of resilience: it comes into companies' equation for several reasons. Primary productivity increase, cost reduction and increase in service level.

Nevertheless, supply chain automation implementation also shows several challenges, first employee resistance to change, lack of skills and of IT readiness, and lack of clear vision: a common mindset towards automation and digital transformation in line with the company strategy is a fundamental prerequisite to ensure success of supply chain automation initiatives. In addition, implementation costs and integration of technologies with other company's systems and technologies are relevant barriers.

2.2. Research questions

If it is true that the concept of automation applied to business processes and information in the supply chain is being widely studied, is also true that a lack of a comprehensive overview about "supply chain automation" is missing. Only 2 out of 52 articles reported a specific definition of "supply chain automation" and seven papers expressed the need to deep dive into different roles and potential of technologies in automation of the supply chain. Supply chain automation indeed, has been receiving more attention from practitioners and vendors rather than by researchers. As a result, the academic community has, to some extent, overlooked the complexities and heterogeneity of options of real-world applications.

As highlighted before, automation potential inside the supply chain is huge, moving from automation of single business processes to locally improve productivity up to the creation of an automated supply chain. In this context, possibilities for approaching and implementing automation are a lot, and differentiate themselves on the base of business processes automated, technologies enabling it, level of complexity and integration, and relevance of their impact on the supply chain management.

Understanding the variegated nature and roles of supply chain automation, is fundamental to identify the best way to pursue it in different scenario, especially to manage the complexity of today's supply chain, where solutions need to be smartly designed and adapted to specific business cases, as well as fitting with the organization's strategy [12].

This thesis aims to fill this gap, giving more clearance to the concept of supply chain automation. Focus is put in identifying the different roles of technologies in this, and their potential and readiness toward an orchestrated integration in the direction of building automated supply chains. Managerial implications for companies willing to identify the best automation roadmap are also provided, given the results obtained from the analysis. For this purpose, the following research questions are analysed:

- RQ1 – Which are the key technologies available for supply chain automation?
- RQ2 - How can supply chain automation be operationalized?
    - RQ2.1. - Which technologies are more suited for automation of which business processes?
    - RQ2.2. – What is the technological readiness of supply chain automation in the direction of building an automated supply chain?
- RQ3 – Which are the managerial implications of SCA?

2.3. Work structure

A literature review has been performed, to understand the state of art of research about supply chain automation and technologies suitable for its implementation. The methodology is reported in Chapter 3, and description of identified gaps in Chapter 4. In the same chapter, justification and deeper explanations of research questions is reported. The main findings of the literature review, that answer the research questions are discussed in the following chapters. Chapter 5 provide a comprehensive view of current the state-of-art of supply chain automation concept. In Chapter 6 technologies suitable for supply chain automation are described, focusing on 1) technological aspects, 2) reasons behind adoption, 3) benefits and 4) main limitations and challenges of implementation. Automation enabled by different technologies is reported, on the base of application described in literature. Following, Chapter 7 carries out analysis to identify the best fits, among technologies previously identified and potential for automation of different business processes. Chapter 8 goes forward with the analysis, taking into consideration more complex automation, requiring integration of different technologies and with a wider impact on supply chain. Their technological side as well as level of development in the scope of building an autonomous supply chain is analysed, to carry out conclusion regarding the level of readiness of technologies and their integration in automating the end-to-end supply chain. Finally, managerial implication are considered, analysing different technologies and automation frequency, benefits, challenges, and relevance in integrated automation. The goal is to provide insights for identification of the best way to approach automation, and to implement it through a roadmap (Chapter 9). Main conclusions from findings are then reported and discussed in the Chapter 10, together with limitations of the work and future research directions.

3 Methodology

In this section the systematic literature review methodology followed to answer the thesis research question are explained.

3.1.1. Query structure

The systematic literature review was carried out with research on the Scopus database that, being the largest database of peer reviewed literature, has been considered as the primary source for papers selection.

Since the focus of the thesis is to deep dive into the automation of business processes and information ones in the supply chain, the query was structured as follow:

TITLE-ABS-KEY ("supply chain" AND "process automation")

The research returned 137 papers that were screened through the following string:

AND (PUBYEAR > 2014) AND (PUBYEAR < 2024) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "BUSI")) AND (EXCLUDE (DOCTYPE , "ch") OR EXCLUDE (DOCTYPE , "bk"))

Explanation of the applied constraints:

- Publication year: only papers published from 2015 to 2023 (current year of research) were taken into consideration. This decision was made due to the fast pace of evolution of technological possibilities in the scope of supply chain automation, that change and evolve constantly.
- Subject area: the areas of "Engineering" and "Business, management, and accounting" were considered in line with the purpose of the research.
- Document type: "books" and "books chapter" were excluded from the search, limiting it to "articles", "conference papers", "review" and "conference review".

After these steps a total amount of 45 documents was reached.

All documents were read in detail, and:

- 9 papers were excluded since not available online or not for free.
- 12 papers were excluded from the research since out of scope of the analysis.
- 18 papers were added to the literature review. These papers were identified in the references of others and appeared interesting in the scope of the research.

Leading to a total of 42 papers.

3.1.2. Papers analysis and classification

For the final total amount of 42 relevant papers, the following information have been extracted and kept track of:

- Author
- Document title
- Publication year
- Source title
- Volume, issue, page
- Number of citations
- DOI
- Link
- Abstract
- Author keywords
- Document type
- Publication stage

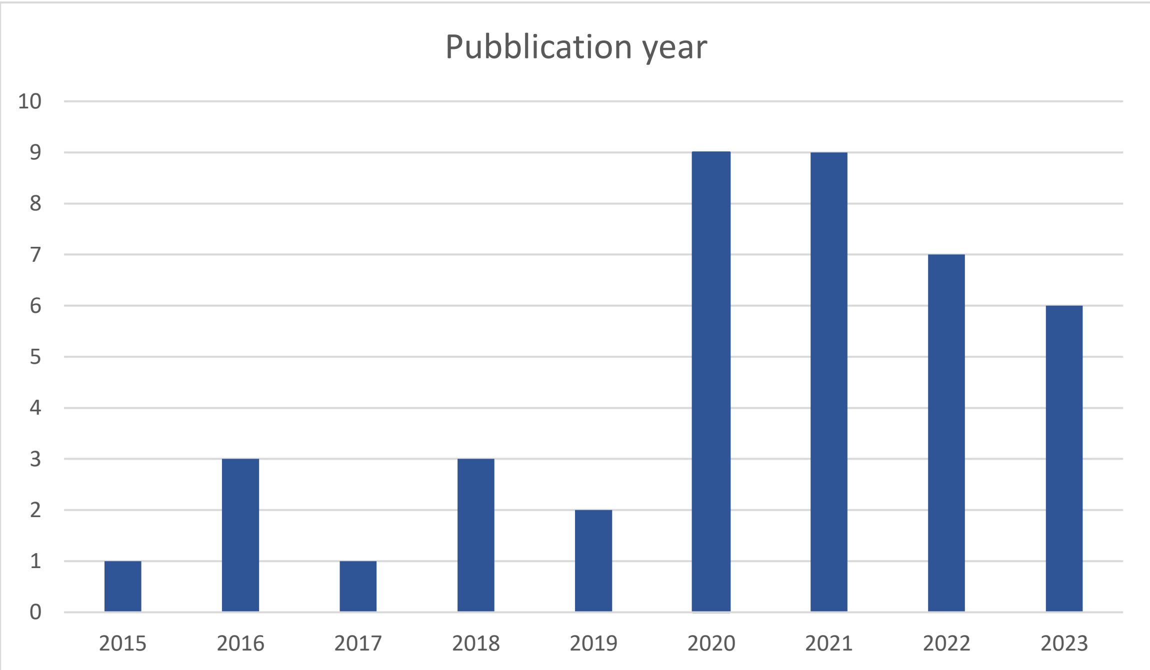

Figure 1: papers' publication year

From analysis of publication year (Figure 1), it appears evident that interests toward supply chain automation exploded from 2020, year that together with 2021 represent the peak of articles' publication year. It was during the Covid-19 pandemic indeed, that supply chains really understood the power of resilience and automation to ensure smooth running of operation even in disruptive contexts. After 2020 it was clear that nothing would have been the same: technological advancement run even faster and attention of researchers and managers towards ways to ensure resilience and boost competitiveness became even more relevant. The amount of paper registered for 2023 is lower than previous years (2020, 2021, 2022): the results is surely influenced by the fact that the research was conducted in the month of June 2023.

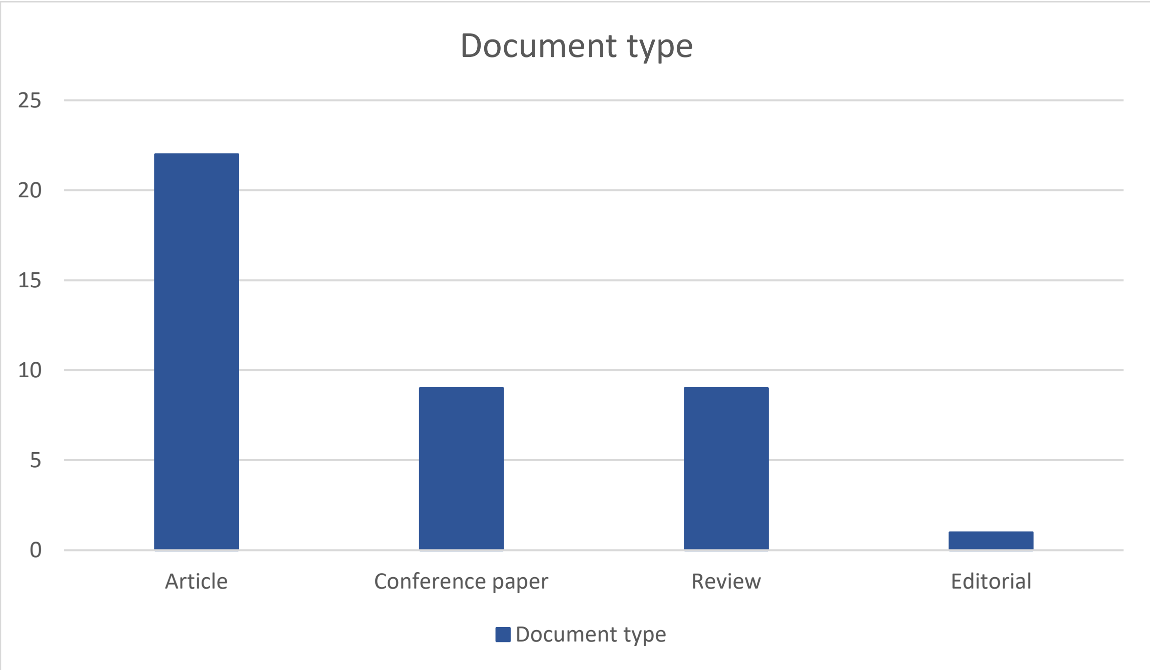

Figure 2: Papers' document type

As highlighted in Figure 2, articles are the most relevant among document types, followed by conference papers and reviews.

For each paper, after an in-depth analysis, the following information was added, since considered relevant for the research:

- Relevance of the paper in the scope of the research and main contribution.
- Technologies analysed by the paper in the scope of supply chain automation.
- Goal of the proposed automation.
- Focus on specific industries.
- Future potential of the research.
- Limitation of the research.

3.1.3. Grey literature

In addition to the 42 papers identified through structured paper selection on official review literature databases, 10 papers were added in the scope of the research. These papers were found in the following way:

- Published from the leader in the supply chain business process automation sector. The providers in question are Automation Anywhere, UiPath and Blue prism. Their websites were analysed in depth to gain a further knowledge of what the market is currently offering, and two papers were identified as valuable for the research.
- Published from leading consultancy companies, that actively research and operate in the field of supply chain automation. In particular, the companies that showed interesting grey literature in the scope of the research are McKinsey and company, Boston consulting group, Deloitte, Capgemini.

As in Figure 3, all papers were published later than 2017:

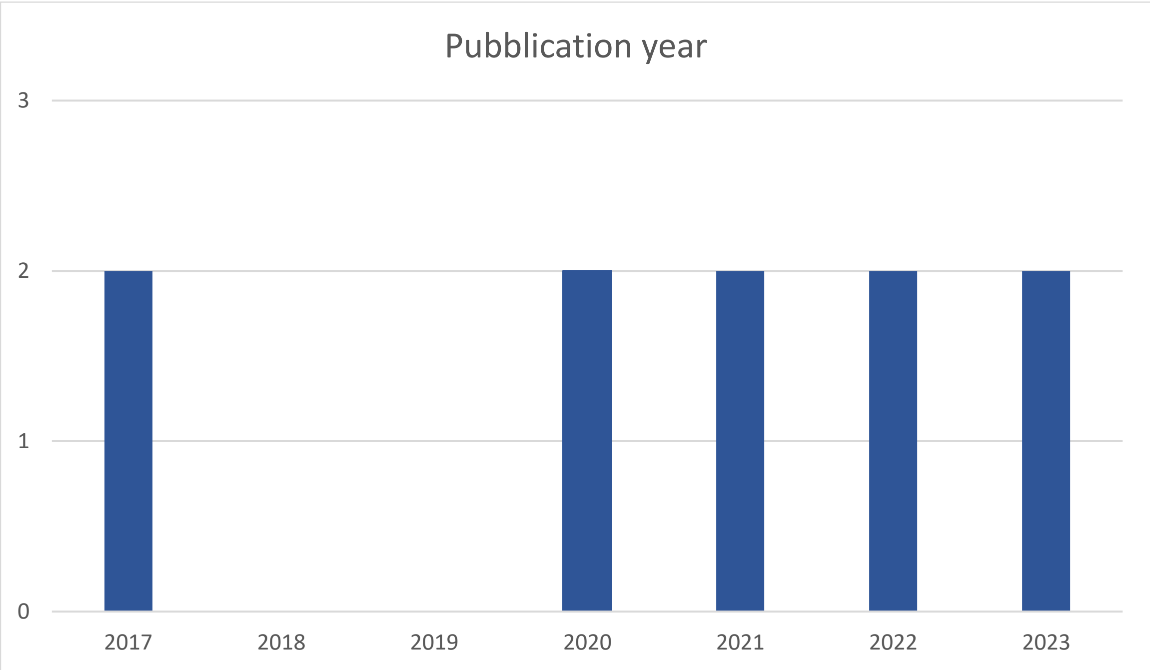

Figure 3: Grey literature papers' publication year

The final total amount of papers taken into consideration for structuring the literature review is therefore 52. In Figure 4 the papers' selection funnel is graphically reported:

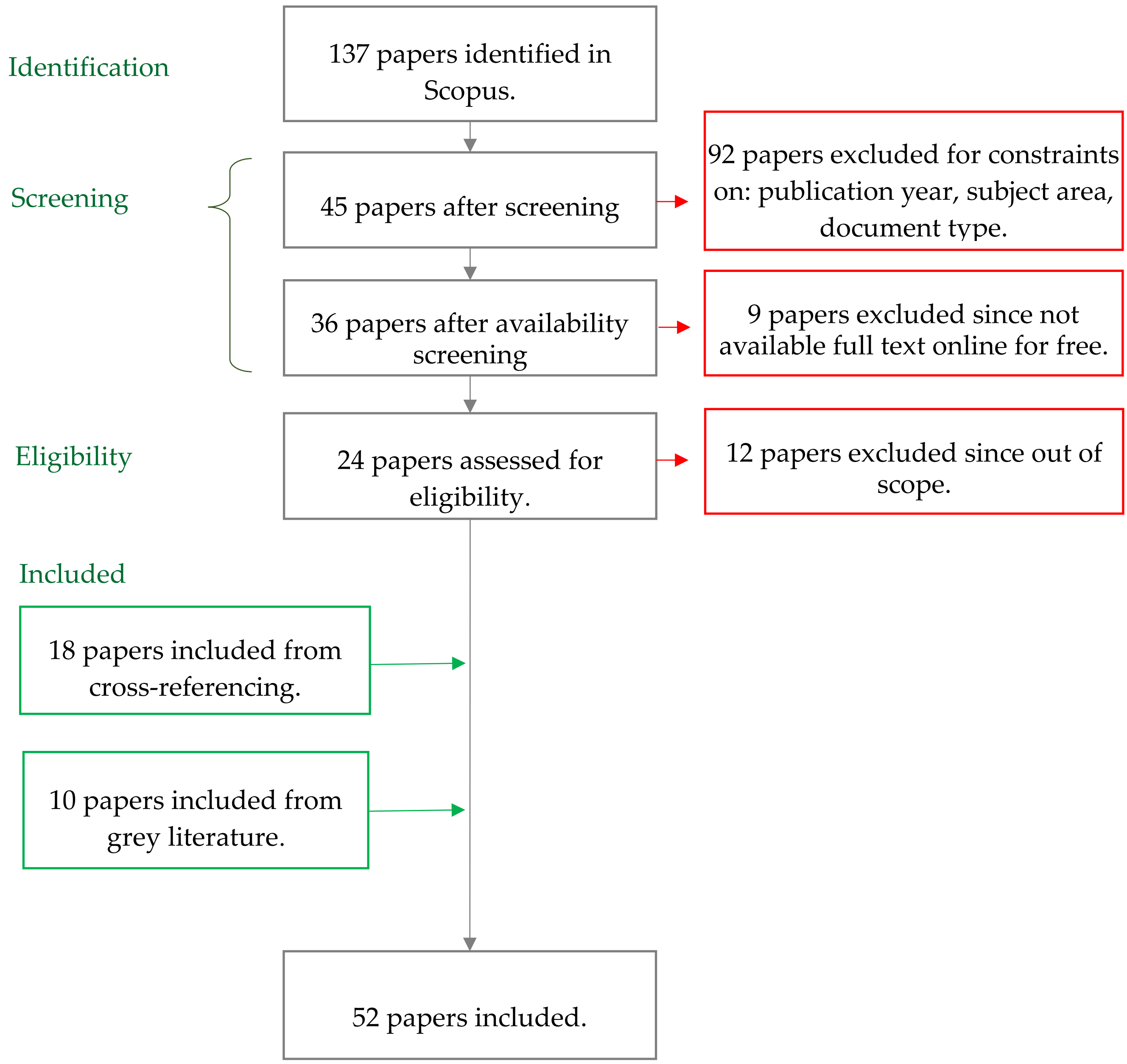

Figure 4: Papers selection funnel

4 Research objective

If it is true that the concept of automation applied to business processes and information in the supply chain is being widely studied and discussed by academicians, is also true that a lack of a comprehensive overview about "supply chain automation" is missing.

First evidence is given by the fact that only 2 out of 52 articles reported a specific definition of "supply chain automation" before introducing such applications, showing that a unified view of this concept is still not widely accepted, nor available.

Seven papers ([6] [8] [9] [13] [14] [15] [16]) among the analysed ones, point out in "future research" the need to deep dive into different technologies roles to automate different business processes, or different technologies roles for automation of different supply chain stages. Hartley et. al. in [8] ask a specific question, particularly in line with the research objective: "Which supply business processes stand to benefit the most from which digital technologies and why?"

Supply chain automation indeed, has been receiving more attention from practitioners and vendors rather than by researchers. As a result, the academic community has, to some extent, overlooked the complexities and heterogeneity of options of real-world applications. Indeed, several aspects of this concept emerge from the performed systematic literature review, highlighting the huge variety of possibilities present for automation of the supply chain. These encompass different business processes, through different technologies, at different level of complexity and integration.

Given the current situation, it may be hard for companies to identify the best way to pursue supply chain automation on the base of their needs. Selecting the right option and implement it in a correct way is critical, especially to manage the complexity of today's supply chain, where solutions need to be smartly designed and adapted to specific business cases, as well as fitting with the organization's strategy [12].

This thesis aims to fill this gap, giving more clearance to the concept of supply chain automation. Focus is put in identifying the different roles of technologies enabling it, and their potential and readiness for an orchestrated integration in the direction of building an automated supply chain. Managerial implications are also analysed, to help companies identify the best automation roadmap to approach to this concept. For this purpose, the following research questions are analysed:

- RQ1 - Which are the key technologies available for supply chain automation?
- RQ2 - How can supply chain automation be operationalized?
    - RQ2.1. - Which technologies are more suited for automation of which business processes?
    - RQ2.2. - What is the technological readiness of supply chain automation in the direction of building an automated supply chain?
- RQ3 - Which are managerial implications of supply chain automation?

5 Supply chain automation - SCA

A comprehensive definition of the concept of supply chain automation is still not widely accepted. Almost all papers describe single or multiple technologies application in the scope of automation of the supply chain, but only two papers provided an extensive definition of it, as reported in Table 1:

Table 1: SCA definitions

Reference	SCA definition
[4]	"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".
[5]	"Ability of the supply partners to automate financial, physical, activity, and information workflows across the SC. It involves integrating disruptive digital and operations technologies that reduce the dependencies of SC operations on human interventions"

Definition of supply chain automation can be synthetized as: "The partial or full replacement 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. It involves integrating disruptive digital and operations technologies that reduce the dependencies of SC operations on human interventions."

While physical automation in the context of manufacturing is an ongoing topic with numerous innovations, the scope of automation nowadays is much broader [7]. Current work automation efforts commonly focus on automation in a digital manner, targeting work that is related to the interaction between humans and computer [7]. The so-called informational automation separates itself from physical automation and represents one of the most significant developments on the planning and control of supply chains at the strategic, tactical, and operational levels [4]. At the same time, they represent a high source of complexity since it involves aligning and integrating multiple partners wills, data, and system in complex global networks.

The focus of this thesis is about business process and information automation only, and SCA in the scope of physical flows and movements will not be taken into analysis.

5.1. Supply chain automation benefits

Automation typically comes into the equation of supply chains for two interrelated reasons: the need to optimize processes and the desire to control costs [6]. But typically, reasons driving supply chain automation initiatives are several and companies often consider a combination of these [4]: other benefits common to supply chain automation initiatives are enhanced supply chain resilience, improve in processes' quality, and improved customer experience.

Improve people productivity.

[2] refers to productivity increase as the primary driver of automation effort, that is often becoming a necessary condition to remain competitive in the market. According to [2] 76% of companies implementing automation choose productivity as the top KPI to measure the impact of the related investments. Productivity enhancement is the fruit of several interconnected elements. From one hand, autonomous solutions are faster and more accurate in execution, and on the other hand workers can focus on more strategic and critical tasks since they do not have to account for repetitive and non-value adding tasks anymore. This improves the overall supply chain performance and boost employee motivation and satisfaction [2]. Higher level of outputs raised quality, speed, agility, safety, and fewer errors are cited by [17] as main benefits leading to overall productivity increase.

Reduce operational costs through better decision.

Cost reduction is one of the main drivers in companies' effort towards automation [2]. In report [1], a survey on 441 executives of a wide range of industries from 29 countries was performed. Results showed that automation initiatives in the supply chain led to an average cost reduction of 24% yearly in the areas targeted by automation. The most cited cost items to benefits from supply chain automation is inventory holding costs, since more accurate inventory planning and related decision making can lead to optimized levels of inventories in the warehouses [18] [12] [3].

Increase of processes quality

Reduce reliance on manual data entry and transfer is the first element that is leading to data quality enhancement, thanks to elimination of human errors. In the same way, automation of tasks and process execution ensure that these are performed without mistakes, consistently, and in a standardized way. Improved process quality and compliance is also arising from the higher data integration and visibility achievable through SCA.

Increase resilience.

Increase resilience to complexity and disruptions, as well as better agility and responsiveness of supply chain networks are reported as major benefits arising from supply chain automation [12] [19] [11] [20]. [5] identifies in supply chain automation the most critical component for pursuing supply chain resilience, stating that it should be the first area to be addressed in the path towards digitalization of the supply chain. Need for resilience arises from the increasing complexity and uncertainty to manage, and recent history events, first Covid-19 pandemic, have highlighted its fundamental importance to boost survival and competition [11]. Increasing number and types of actors in the supply chain, market volatility, longer and interlinked physical flows and increasing complexity of product portfolio, are reported by [12] as drivers of complexity in modern global supply chains. Supply chain automation, thanks to increased data quality and integration, connectivity, visibility, transparency, and intelligent support in decision making, helps supply chain in reaching this scope [11]. Effective automatic decision making rely on data and on the use of intelligent technologies and networks able to leverage on this data to provide timely, targeted, data-driven, optimal and feasible recommendations, insights and decisions. [19]. This also answer the need for independence from decisions relying on individuals' knowledge and expertise [4].

Improve customer experience.

By automatizing business functions and processes, one of the main registered benefits is the increase of the service level offered to customers [12] [21] [2] [19]. Possibility of real time tracking of orders, flexibility in responding to changing customer demands, personalized recommendations, simplified payment processes [21], real time acquisition and manipulation of market data to identify interactions among customers and products [14] are some examples described in the papers that, together with previously analysed benefits, lead to an enhanced customer experience. [22] select buyer handling time as major service-level KPI impacted by the automation initiative implemented in the company "Maersk".

5.2. Supply chain automation challenges

Several barriers exist in implementing supply chain automation initiatives, that slow down their diffusion and challenge their success. The following are the most critical ones, according to literature:

- Process fragmentation. Companies often work with immature and fragmented processes, not managed in a unified flow, often on disconnected systems [1]. This makes implementation of automation much harder.
- Lack of IT readiness. Organizations often rely on legacy IT functions to achieve automation, and this can be limiting. In addition, different platforms, information systems and standards may be used by different actors in the supply chain, and this increases the complexity of automation [4] [23] [24] [25] [20]. Integration of automation initiatives in the existing systems and interoperability among different systems is a related challenge to be addressed [4] [23] [24] [17] [14]
- Data quality and availability. Supply chain automation require an adequate amount of data to run, and quality of data is also relevant, if benefits from automation wants to be reached [4] [24]. Not only data needs to be available, but they also need to be effectively analysed and manipulate to exploit their potential. Big data management readiness is therefore another necessary condition to implement automation and thus may represent an additional challenge for companies [25].
- Lack of a clear vision. Necessity to develop a common mindset towards automation and digital transformation in line with the company strategy is a fundamental prerequisite to ensure success of supply chain automation initiatives. To reach this goal support and commitment of top management in RPA implementation journey plays a critical role [13] [26] [22] [4]. Indeed, once a direction is set, organisations can more effectively prioritise the right processes for automation, and follow a digital roadmap to growth [27] [23]
- Resistance to change. Employee may not be familiar with automation technologies. Resistance to change the usual working methods and fear of being replaced by technology with consequence job lost are critical barriers [27] [24]
- Lack of skills. Employee often lack the necessary skills needed to evaluate, implement, use, monitor and maintain automation and its underling technologies [20] [24] [4]

- Cost. Cost of buying, adapting, implementing, maintaining, and integrating the necessary technologies required to automate activities can be expensive and complex. In addition, economic benefits evaluation is not always easy to assess in advance [25] [20] [24].
- Privacy, confidentiality, and security concerns. [4] [20]

5.3. Supply chain automation in different industries

Table 2 shows all papers which focus specifically on a certain industry in the analysis of supply chain automation.

Table 2: industry focused papers

Reference	Industry focus
[28]	Finished vehicles logistics
[13]	Electronic
	Pharmaceutical
[29] [30] [31] [25] [32] [33]	Food
[22]	Logistics
[34]	Semiconductor
[16]	Intermodal logistics

Only 11 articles out of 52 focus on specific industries. Food industry results by far the most analysed one, followed by logistics, that is also taken into account in different forms.

Reasons behind deep interests for processes automation in food supply chains, lie in the strict requirements for food safety and the constant shift of regulations [25]. Attention toward food quality has always been high, but the globalization trend has amplified the concerns of consumers regarding food safety and quality [32], given the longer distances between the locations of food production and consumption and the great number of actors involved. This mean that necessity to make food supply chains more transparent through effective traceability systems is a must, to provide customers fast and trustworthy way to retrieve necessary information on food products [32]. Effective traceability systems are also studied as a mean to reduce waist: according to [31] about 360 million tonnes of perishable foods are lost annually due to insufficient use of refrigeration. In this context, real-time visibility, and automatically proactive notification for remote users to reduce risks is important [31]. All articles deep dive into this requirement.

6 Technologies for SCA

Papers report and discuss several technologies to integrate in information systems and daily activities for automating different types of processes. Adoption of technologies for automation of the supply chain represents a shift in how value is created, enhancing supply chain resilience through principles such as interoperability, real time capability, modularity, decentralization and integrability that enable the concept of hyperconnected value creation system [5]. The following sub-chapters describe them in detail, reporting the identified automation enabled by each technology:

6.1. Robotic process automation - RPA

Robotic Process Automation (RPA) is an emerging technology that uses virtual robots to mimic human interactions across various systems [13]. Several definitions were found in the papers and reported in Table 3.

Table 3: RPA definitions

Reference	RPA definition
[8]	"RPA is software that performs routine process tasks such as an automated email response based on simple rules"
[9]	"A preconfigured software instance that uses business rules and predefined activity choreography to complete the autonomous execution of a combination of processes, activities, transactions, and tasks in one or more unrelated software systems to deliver a result or service with human exception management"
[13]	"Programmed software robots that mimic repetitive manual tasks performed by human workers and replace these workers"
[22]	"Software that assigns a logon ID to a software robot to perform digital tasks that were previously performed by humans"
[35]	"A technology that allows anyone today to configure computer software or a "ROBOT" to emulate and integrate the actions of a human interacting within digital systems to execute a business process"

Synthetising this table, RPA can be defined as "a preconfigured and programmed software robot that automate repetitive manual tasks emulating human workers and their interactions with digital systems. It uses business rules and predefined activity choreography to automate the execution of a combination of business processes, activities, transactions, and tasks in one or more unrelated software systems to deliver a result or service with human exception management".

6.1.1. Reasons behind RPA adoption:

RPA is often companies' first step toward automation due to its relatively easy and fast implementation process [8], in addition to the fact that supply chains have many repetitive tasks that can be automated trough RPA [8]. In paper [1], 441 companies from 29 different countries were interviewed in the matter of level of supply chain automation: RPA appeared to be the most widespread technology, with 78% of interviewed companies already implementing it, and 16% planning to do it in the next three years. Main reasons behind RPA adoption are here reported:

- It works "on top" of existing software and information systems and through the existing user interface, without changing the underlying software architecture [9]. It can therefore run and move across existing systems [13]
- It is easy to introduce in the company, due to limited training and coding skills necessary to use it, and to high availability of providers in the market [8].
- It is easy to add or remove capacity and to scale up or down bots depending upon business needs [8]
- Relative low investments [8]
- It can be applied to single tasks in a process, without having to re-design and re-engineering the end-to-end process. [9]

6.1.2. Processes suitable for RPA applications:

RPA typical applications include data entry, data transfers, simple calculations, reading and extracting data from Enterprise Resource Planning (ERP) systems and form completion [8] [13]. More in general, processes suitable to be automated with RPA have the following attributes:

- Repetitive. High and predictable transaction volumes are required. Best suited process to be automated with RPA are the routine ones, that are repeated hundreds of times daily without changing over time [13].
- Rule based. Tasks need to be relatively easy and well defined by unambiguous rules, since robots require precise instructions. Also input and output needs to be clear and standard. [22]
- Stable environments. Very limited exception handling is manageable by RPA applications; therefore, the situation needs to be stable without significant changes and variables [22]

- Mature process, that are present in the company operations for a while. [22]

It has been shown that transactional tasks, long and high-volume processes are the ones where implementation of RPA can register the amplified benefits [36].

6.1.3. Benefits of RPA:

Main benefits registered by companies implementing RPA into their supply chain are:

- Increase in productivity since it allows to free employees from nonproductive tasks, so that they can focus on higher value ones, more tactical and strategical [22] [13].
- Processing time reduction, thanks to robots' ability possibility to work h24, with consequent cost reduction. [37] [13]
- Compliance levels improvements, since it eliminates human errors, improves data quality, and processes accuracy [9], with overall lowers compliance risk [13]

RPA technology not only gives organisations an opportunity to automate their processes, but also helps them to simplify and rapidly streamline them [9], leading to increase of agility and transparency between different actors of the supply chain [35].

6.1.4. RPA limitations and challenges

Main difficulties and challenges in RPA implementation lie in:

- Resistance to change. Workers may not be willing to introduce RPA since it would mean a change in their daily tasks and roles with eventually new skills to acquire. In addition, they may fear job loss. [9] [36] [22]
- Lack of a clear vision, or of a digital transformation roadmap. To ensure RPA success, support and commitment of top management in its implementation journey plays a critical role [13] [26] [22]. Evidence shows that nearly 30% - 50% of RPA initiatives fail even though they have all functionalities within the implemented software robots: the root cause is to be found in managerial rather than technical issues [36]. Firms indeed, tend to overestimate the potential gains, while lacking the organisation skills needed to implement the tool [9]
- Process requirements. In order to successfully capture RPA benefits, processes prior its applications need to be mature, standardized, and well-defined [9] [13] [36]. The identification of the right process to automate is itself often challenging [36]. In addition, firms must make sure that the process is working well before

automating it, and understand how automating one part of it might affect its overall performance [8]

6.1.5. RPA-based SCA: classification

Table 4 shows RPA-based automation initiatives classified on the base of which supply chain stage they work on:

Table 4: RPA-based automation

SC stage	Reference	Process automated through RPA
Procurement	[9]	Placement of orders based on stock level, create order receipt invoices
	[22]	Purchase- to-pay process. *Solution achieved thanks to integration with AI*
		Develop suppliers' performance scorecard
	[8]	Procure-to-pay processes: RPA can create and send requests for quotations; compare supplier bid responses to predetermined criteria; create purchase orders; match purchase orders, invoices, and receiving documents; and process payments.
Production	[34]	Production scheduling over a weekly time axis, after assignment of customers' orders based on a set of weighted criteria that is dynamically adjustable.
	[21]	Master data creation, maintenance, and transfer.
	[13]	BOM creation. RPA open GSCM under assigned ID, and then download material master from the system. It then login to SAP and download the second material list via a BOM list download t-code. Next the robot matches material data between two downloaded sheets and generates final version of shortage components to upload on SAP. Any not-found issue is recorded and reported. If issues occur due to disconnections between systems RPA will send an alert for mismatch errors to system users.
Transportation	[22]	Route optimization. *Solution achieved thanks to integration with AI*
	[8]	Enter information from documents to transportation management system (TMS), schedule and track shipments
Inventory	[36]	Enter customer order data in the warehouse management system (WMS). *Solution achieved thanks to integration with Cloud technology*
Demand	[35]	Manage the customer claims handling process. ISCQ will send the communication to respective stakeholders and wait for immediate response. If the immediate response will not be updated in the ISCQ, the RPA will send the escalation to management with a warning notification. In case of repeat claims RPA go back to the product

		directory and search the similar product and process and give the trigger to process owner for horizontal deployment. If the same failure mode was not captured it will also send the trigger to process design engineer. *Solution achieved thanks to integration with Cloud technology*
	[8]	Enter and consolidate orders from multiple customers

6.2. Advanced analytics

Artificial intelligence and big data analytics technologies are analysed under this category. For the SCA scope, their analysis on benefits, challenges and role in automation can be conducted jointly.

6.2.1. Artificial intelligence – AI

Artificial intelligence applications in the supply chain automation scope are surely among the most relevant ones, given the huge capabilities opened from AI. Table 5 shows all found definitions of AI in the scope of supply chain automation:

Table 5: AI definitions

Reference	AI definition
[8] **[15]**	"Technology that has a system's ability to correctly interpret external data, to learn from such data, and to use those learning to achieve specific goals and tasks through flexible adaptation"
[30]	"Scientific and technological expertise for the development of smart computer programmers"
[1]	"Technologies able to process unstructured data and automate tasks that previously required human intelligence or judgment"
[19]	"Ability to analyse huge volumes of data, understand relationships, provide visibility into operations, and support better decision making"

Synthetising this table, AI can be defined as a "Technology that has a system's ability to correctly interpret data, understand relationships, learn from such data, and use those learning to achieve specific goals and tasks through flexible adaptation, providing visibility into operations, and support better decision making."

Machine learning (ML)

Machine learning is a subset of AI that uses algorithms to analyse and extrapolate patterns in data [8] and learn automatically from them, without being explicitly programmed for that [30]. Models build on data are used for making data-driven predictions and decisions by individuals, corporations, and organizations, and are especially needed when information are highly complex and unpredictable [30]. It represents the most interesting and discussed AI-based technology for automation. An important distinction needs to be made [30] about different ML types:

- Supervised learning: the computer is through a categorization system built by humans. It is commonly used for training neural networks and decision trees.
- Unsupervised learning: the system is given a collection of data and is charged with identifying patterns and correlations in it. It uses unobservable input patterns, as well as a priori knowledge of significance.

6.2.2. Big Data analytics (BDA).

Big data is a "technology that treats ways to analyse and systematically extract information from large data sets". These data sets are too large or complex to be dealt with by traditional data-processing application software and rely on advanced analytics techniques. Indeed, the significance of big data technology is not to hold huge data, but to extract effective information contained in the data by specialized data processing [15]. Big data can be described by the following characteristics [38]:

- The big quantity of generated and stored data
- The variety of type and nature of the data
- Real-time data processing velocity
- High data quality and value

Business analytics is a process through which mathematical techniques and functional ones are combined to yield actionable insights: they often incorporate AI/ML algorithms and techniques. Indeed, advanced analytics of big data answer to the need for faster and better decisions: Survey shows top-performing organizations use analytics five times more than lower performers [6]. To capitalize on big data, firms need to source the right data, build models that predict and optimize business outcomes, and transform organizational processes [6] s. For this reason BDA implementation is usually paired with IoT and Cloud computing, that provide the extensive big dataset.

6.2.3. Reasons behind Advanced analytics adoption

AI and BDA enable companies to automate processes with characteristics that would have been impossible with RPA alone, expanding automation capabilities and accelerating decision making [39].

This arises from the cognitive capabilities enabled by AI and BDA, including recognizing known and novel patterns and categories, logical reasoning and problem solving using contextual information and increasingly complex input variables, optimization and planning to achieve specific objectives given various constraints, creating diverse and novel ideas or combination of these, searching and retrieving information from a large range of sources, interacting with other machines and with humans to coordinate group activity, and output articulation and presentation, which involves delivering outputs other than through natural language [17]. In addition, natural language processing is also involved, meaning the ability to deliver spoken messages and to understand in all its complexity natural languages [17]. Therefore, application areas where Advanced analytics can really make the difference, are linked with its potential to:

- Handle and determine the uncertainty [39].
- Automate highly variable work [39].
- Process unstructured data, learning to recognize patterns and accurately process information within them to extract their meaning [39].
- Treat problems with exceedingly complex analytical solutions [30].

Advanced analytics holds the potential to dramatically improve supply chain performance pursuing a global rather than a local optimum [18].

6.2.4. Benefits of advanced analytics

Benefits registered from AI and BDA adoption in supply chain automation are not negligible, specifically:

- Higher responsiveness and increase of supply chain resilience [11], thanks to higher connectivity, transparency, and visibility, that make supply chains more effective especially in volatile environment [18].
- Lower costs [12], by optimizing operations and improving profitability [29]. [18] states that Advanced analytics application in for automation lead to a supply chain cost reduction of 10%, with major focus on logistics costs [12]
- Faster and better decisions making. Advanced analytics ability to recognize patters of data that humans cannot see, make of this technology a powerful enabler of timely and accurate decision making, prediction, and planning [38]. Direct consequences are lower inventory level and higher service level [12]. The latter is also determined by the increase in responsiveness that allow to better answer to changing consumer needs and market dynamics [18].

6.2.5. Advanced analytics limitations and challenges

Main difficulties and challenges in AI and BDA implementation lie in:

- Data availability and quality [8] [38] [1] [17] [39]. Presence of good quality high volume data is essential to ensure Advanced analytics solutions to work effectively [11].
- Lack of knowledge and skills [8] [38] [1] [17] [11] [12]. Skilled workforce is a must for implementing and managing AI- and BDA- based automation in an effective way [17], due to their complexity.
- Resistance to change [8] [38] [1] [17], often linked with the presence of regulatory and ethical concerns increase this need [1] [39]. Smooth change management and organizational readiness is needed, meaning alignment between strategic vision, managers objectives and systems [12].
- Lack of a clear vision towards AI- and BDA-automation [8] [1] [17]. This led to the fact that companies often struggle in the identification of the most suitable processes or use cases for advanced analytics [39]. In addition, companies tend to focus on AI/BDA implementation in single functions rather than having an end-to-end supply chain optimization vision in mind, leading to sub-optimal results [38].
- Integration challenges [1] [17]. According to [39], many interesting Machine learning models are underutilized or ignored by companies, because business users do not know how to integrate them in their day-to-day business processes.
- Uncertainty about economic benefits, due to difficulty in assessing concrete impact on the company’s ROI [1] [8].
- Concerns linked with privacy and security [1] [17] [39]. Especially considering the high volume of big data needed to run AI-based automation, companies often have security concerns [15].
- Cost of implementing, running and maintain the solution [1].

6.2.6. Advanced analytics based SCA: classification

Table 6 shows all AI- and BDA- based automation initiatives found in the papers, classified on the base of which supply chain stage they work on:

Table 6: Advanced analytics-based automation

SC stage	Reference	Process automated through AI and BDA
Procurement	[8]	Cognitive sourcing platform to provide sourcing recommendation (ML). *Solution achieved thanks to integration with Cloud computing*
	[33]	Create electronics invoices
	[40]	Semi-automatic procurement. When the storage's stock of a specific production input part is low i.e., below a specified threshold, the bid specification is registered. Parameters are detected through a set of IoT sensors. The bid specification is then reviewed and possibly enhanced by a human. Subsequently, the process execution engine starts a loop that automatically updates the bid specification based on the latest sensor data from storage and production environment, and then registers bids for the to-be-procured good. If an anomaly in the production line environment is registered, the agent interprets the received sensor data to assess whether the bidding should be stopped. If so, the process is terminated. *Solution achieved thanks to integration with IoT*
	[22]	Purchase- to-pay process. *Solution achieved thanks to integration with RPA*
	[14]	Web based e-procurement. Information are acquired, stored and elaborated to support daily business and administrative tasks, as well as complex decision-making. *Solution achieved thanks to integration with IoT, Cloud*
Production	[15] [8]	Schedule maintenance ([8] ML, [15] BDA). *Solution achieved thanks to integration with IoT*
	[15]	Packaging recommendation
	[41] [21] [30] [42] [11] [15]	Predictive maintenance (ML, BDA [15]).
	[23]	Cloud based service-oriented Tool management (TM). Through a unique and standardized identification scheme based on serialized numbers, tools' data are captured and stored in remote store locations in the cloud. Several services are deployed, to support an efficient collaboration among all parties involved: core business services focus on generating, calling, updating, and visualizing tool relevant data, and enable automatic set-up of machines. In addition, value added services are present, such as track and trace, management, and control of the inventory and of equipment maintenance. Analytics methods can also be applied to enable predictive maintenance, breakdowns

		predictions and production planning. *Solution achieved thanks to integration with Cloud, IoT*
	[27] [12]	Schedule production
	[12] [27]	Agile production planning. *Solution achieved thanks to integration with Cloud*
	[11]	Bottlenecks prediction
	[27]	Resource planning. *Solution achieved thanks to integration with Cloud*
	[1]	Cloud-based intelligent automation platform for automatic set-up of equipment. *Solution achieved thanks to integration with Cloud*
	[43]	Monitor plants behaviour, detect anomalous conditions and recommend next. *Solution achieved thanks to integration with IoT*
Transportation	[27] [33] [16] [15] [31] [42]	Route planning ([27] [42] *Solution achieved thanks to integration with IoT;* [31] *Solution achieved thanks to integration with IoT, Cloud)*
	[15]	Distribution network planning (BDA)
	[42] [31] [12] [8] [15] [22]	Dynamic route optimization ([8] ML; [42] *Solution achieved thanks to integration with IoT;* [31] *Solution achieved thanks to integration with IoT, Cloud;* [22] *Solution achieved thanks to integration with RPA)*
Inventory	[8]	Schedule the picking process (ML)
	[42] [15]	Warehouse capacity optimization (BDA). *Solution achieved thanks to integration with IoT*
	[11]	Shortage prediction
	[15]	Warehouse monitoring. *Solution achieved thanks to integration with IoT*
	[44]	IoT-based smart whs management system. Several algorithms have been implemented to improve the flow of supply chains, such as adaptive task planning, tasks optimization, and path planning (for the picking process). *Solution achieved thanks to integration with IoT*
Demand	[8] [12] [27]	Demand planning
	[8] [12] [14] [30] [15] [11] [27] [5]	Demand forecast ([15] [5] BDA)
	[15]	Predict customers behaviours

	[12]	Price forecast
All stages	[15]	Risk prediction (BDA)
	[27] [21]	Detect problems or changes in processes
	[27]	Propose recommendations and adjustments through real time feedback (BDA)
	[27] [42]	Make decisions. *Solution achieved thanks to integration with IoT*
	[26]	Provide recommendations about potential business partners (ML)

6.3. Cloud computing

"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [42]. The main objective of this technology is to use huge computing and storage resources under concentrated management, enabling the delivery of computing services such as servers, storage, databases, networking, software, analytics, and more applications through visualized and scalable resources over the Internet [25]. These operate on the data and provide automatic means to access, update, aggregate, transfer, process and visualize it in a way that is meaningful to provide integrated functionality [23].

6.3.1. Reasons behind Cloud adoptions

Cloud computing represents one of the future enabling technologies of automation [1], thanks to the achievable real time availability, visibility and integration of data and resources [27], both static and dynamic ones [23], on the internet rather than on local infrastructure [42]. These attributes allow development of ad-hoc applications, algorithms, and functionality to automate different types of information delivery and communication within the cloud eco-system in the supply chain [23], in particular automated planning. In addition, its capabilities can be further exploited as a starting base from other technologies pursuing automation [15].

Reasons behind its high diffusion are:

- Make data location- and time- independent, meaning that they can all be easily remote accessed, whenever and wherever is needed [8] [31]. Cloud is born as a collaborative technology, addressing the common problem of disparate information systems and decentralized data within supply chains and organization [8].

- Scalability. Cloud computing can keep pace with demand and business needs, easily scaling up and down [1]. Additionally, it is fast and elastic in reacting to upgrades and changes [8].
- High computing power [1]
- Fast deployment [1]
- Low costs of implementation [1] [8].

6.3.2. Cloud benefits

For years, large organizations have used on-premises ERP systems to share data and standardize business processes across internal business functions. In the last few years, companies have been moving from on-premises systems to cloud-based systems in which ERP is software as a service (SaaS) [8]. Cloud-based ERP systems offer several benefits over on-premises ones. Cloud ability to allow real-time data integration, sharing, visibility and transparency, make of it a necessary element in the quest for resilience [27]. This imply that companies implementing supply chain automation through cloud register the following positive impacts on their business:

- Better business intelligence and analytics [8], leading to more effective algorithms, enhanced decision support and improved decision making [31].
- Improve efficiency of operations [15]
- Improve service quality [15]
- Enable an efficient and transparent collaboration between all parties involved [23].
- Financial benefits, linked with lower capital investment, lower operating, and lower maintenance costs incurred in the IT department. Additional savings arises from reduced administration and maintenance effort [20].

6.3.3. Cloud limitations and challenges

Privacy and security concerns [8] [31] are reported as main limitation in implementing cloud for SCA.

6.3.4. Cloud-based SCA: classification

Table 7 shows all Cloud-based automation initiatives found in the papers, classified on the base of which supply chain stage they work on. Applications already described in detail in previous paragraphs will only be mentioned.

Table 7: Cloud-based automation

SC Stage	Reference	Process automated through Cloud
Procurement	[8]	Cognitive sourcing platform to provide sourcing recommendation. *Solution achieved thanks to integration with ML*
		Cloud-based procure-to-pay system to automate the entire procurement process.
Production	[12] [27]	Agile production planning. *Solution achieved thanks to integration with AI*
	[23]	Cloud based service-oriented Tool management (TM). *Solution achieved thanks to integration with AI, IoT*
	[27]	Resource planning. *Solution achieved thanks to integration with AI*
	[1]	Cloud-based intelligent automation platform for automatic set-up of equipment. *Solution achieved thanks to integration with AI*
Transportation	[31]	Route planning and optimization. *Solution achieved thanks to integration with IoT, AI*
	[15] [31] [1] [14] [32] [42]	Track and trace shipments and trucks. *Solution achieved thanks to integration with IoT*
Inventory	[36]	Enter customer order data in the warehouse management system (WMS). *Solution achieved thanks to integration with RPA*
Demand	[35]	Manage the customer claims handling process *Solution achieved thanks to integration with RPA*
All	[1] [27] [15] [33] [25] [22] [21]	Resources, data, and process monitoring. *Solution achieved thanks to integration with IoT*
	[15] [31] [27] [1] [32] [8] [21]	Update, transfer, and visualize data

6.4. Internet of things – IoT

Internet of Things (IoT) represents the next step towards the digitization of our society and economy [42], and it is recognized as one of the most important areas of future technologies for supply chains [15]. The definition of IoT is constantly evolving from an original focus on machine-to-machine (M2M) connection and applications to the "ubiquitous aggregation" of data [15]. The IoT definition are described in Table 8:

Table 8: IoT definitions

Reference	IoT definition
[29]	"IoT consists of physical devices that collect data, a network that transmits the collected data, and an application layer which includes IoT applications and services"
[44]	"Network of automated systems that enable the user to control and coordinate devices in the mesh of the Internet"
[42]	"Network connecting anything with the Internet to exchange information and communication, to realize intelligent searching, identification, location, tracking, monitoring and management"
[40]	"Smart Objects (SOs), which comprise a variety of devices like sensors, actuators, mobile phones, and Radio-Frequency Identification (RFID) tags and connect with each other to form a network of objects and cooperate with their neighbours to attain common goals or tasks"

The above definitions can be summarized as follows: "IoT consists of physical devices that collect data, a network that transmits the collected data, and an application layer which includes IoT applications and services, to realize searching, identification, location, tracking, monitoring and management on the internet."

6.4.1. IoT technological structure

The IoT architecture mainly consists of four layers [15]:

- The sensing layer is used to collect and sense various parameters in the physical world by barcodes, RFID, camera, 2-D code, and other advanced sensors [15]. Internet of Things systems require each device to be embedded with a unique digital tag with its detailed specifications [42]. RFID technology is by far the most cited and spread one, described as the "preferential data collection technology" [27].
- The network layer consists of data communication and networking infrastructures for delivering data gathered from devices at the sensing layer to higher layers through the Internet [15].
- The processing layer provides a facility for data access, storage, and processing combining with hardware platforms and intelligent algorithms, such as the cloud platform, big data technology, and AI [15]. At present, most of the servers of IoT are deployed in the cloud, enabling effective organization, integration,

and visibility of the large body of collected data and providing various added value services through cloud computing [42]. In addition, AI-based technologies can take advantage of this to reach a superior and cognitive level of automation. They are able not only to monitor and analyse registered processes, but also to act when conditions are/are not met, detect deviations, and trigger the necessary adjustments as corrective action, without human operators' involvement [25]. More in general, IoT big datasets put the basis for intelligent technologies and algorithms to provide continuous recommendation, predictions, prescriptions, optimizations, and planning [43].
- The application layer provides access services for IoT users [15].

IoT requires a lot of technologies to run including sensor technology and devices, wireless network, and communication technology [15]. Standardization of technologies related to IoT is very important, as it will lead to better interoperability, thus lowering the entry barriers [42].

Most used sensor technologies and devices are:

- Radio frequency identification (RFId). RFId uses electromagnetic fields to automatically identify, and track tags attached to objects. It can be said that RFId converts physical things and the environment into digital data [45]. There are four types of RFID tags according to different frequency ranges, including low-frequency (LF) tags, high frequency (HF) tags, ultrahigh-frequency (UHF) tags, and ultrawideband (UWB) tags. Typical applications for LF RFID tags are wares identification and data collection used in smart warehousing, smart distribution, and smart packaging. HF tags are also most popular in smart warehousing applications, for example for electronic tickets and ID cards. UHF tags are mainly used for smart transportation and UWB tags can achieve precise positioning within half a meter, which facilitates their use in smart logistics [15].
- Wireless sensor network (WSN). WSN refers to a self-organizing network, which is built of tens to thousands of spatially dispersed and dedicated "sensor nodes" for monitoring, recording, and organizing the acquisition data at a central location by wireless connectivity and spontaneous formation of networks [15]. WSN often complement RFID, when wireless sensors are used [32], and has been gained considerable popularity due to its flexibility in solving problems, such as monitoring of transport vehicle status in smart transportation, and item status monitoring in smart warehousing [15]. WSNs are energy-efficient and battery-powered [32].

RFID and WSN are IoT essential technologies: RFID's superior sensing capability and WSN's high ubiquitous capability are combined to create a globally networked object that can be exploited as a resource for automation in an IoT network [45].

In addition, wireless communication technologies and protocols are crucial to enable devices to communicate with others without being physically connected [15]:

- Short range: when there is necessity to transmit signals from a few centimetres to several meters. Most used are RFID itself, Bluetooth, Wi-Fi, NFC (near field communication) and ZigBee, depending on the scenario requirements [15].
- Low power wide-area network: long-distance communication technologies are required for wide-range and long-distance connection. LPWAN technologies are the most popular, meeting above mentioned requirement at low data exchange frequency and low connection costs [15]. A specific protocol in the LPWAN category is LoRaWAN: it uses LoRa modulation technique for long-range and bidirectional communication and support large-scale deployments, in a scalable and flexible way.
- Mobile networks: 4G and 5G are used in long-distances communication when high-speed is a priority [15]. Indeed, Intensive IoT- based supply chains put mobile networks under pressure to provide superior connectivity to machines and smart devices [46]. Application of 5G will be greatly promoted, due to its superior capacity of scaling IoT performances [46]. Its main benefits lie in:
    - Heterogenous structure of frequency bands [15].
    - Ultra-low latency requirements [46] [15].
    - High network throughout, that leads to improved connectivity of all those applications relying on high speed [46]. Connected equipment density is approximately 1000 times 4G's one [15].
    - Network flexibility [46].
    - Low power consumption, determining high efficiency [46].

  The role of 5G is to optimize the connectivity making it real-time to have perfect visibility and monitoring [46]. Using mobile technologies and IoT, enterprises can accelerate productivity, profitability and operations with solutions designed specifically for their processes [42].

Middleware represents the last fundamental technology for IoT good functioning, representing a stable high-level and powerful tool for system integration. Middleware is an independent system software or service program, which can provide a standard data interface. Most middleware architectures for IoT follow a service-oriented approach to encapsulates different operating systems providing an API interface and a unified standard interface for the application [15].

6.4.2. Reasons behind IoT adoption

IoT introduction reflect the following necessities:

- Capture and communicate information in real-time [28].
- Make data and information locally and globally available [8]
- Improve information accuracy [28]. Data are automatically captured and read, eliminating human errors, and improving the overall database quality and volume [8].

Thanks to the accurate high quality and volume information [42] provided by IoT, it enhances end-to-end transparency, visibility, real-time monitoring, tracking, safety and productivity [29]. For these reasons it is a necessary reliable basis for market analysis, execution, forecasting, planning and decision-making [42]

6.4.3. IoT benefits

Positive impacts of IoT introduction in supply chain in the scope of information automation have been registered to be:

- Visibility of operations and processes [29]
- More effective, real-time decision making and planning process since a clearer vision of the situation is available, and supply chains can timely detect problems and react to changes and exceptions [42]. Quality of decision making is also improved by decentralization of control and management arising from IoT introduction [6].
- Higher efficiency and speed of processes [28]
- Improve reliability of real time tracking and traceability systems [32].

6.4.4. IoT limitations and challenges

Main difficulties and challenges in IoT implementation are:

- Privacy and security concerns [42] [45] [15]
- Integration, interoperability with existing supply chain systems and standardization issues. Business users will need to change their systems, assets and organizations in order to make the most of the Internet of Things [42] [45]. The IoT needs indeed many protocols, since ideally, any IoT device should be

able to communicate with any application or service, as well as with each other and with everything they are able to interact with.

- Big data management complexity: IoT implementation will generate a big dataset, that needs to be analysed and processes: data collection process in field of IoT also requires particular and different protocols. Processing large amount of data in real time will increase workloads of data centres, leaving providers facing new security, capacity, and analytics challenges [42] [15].
- High cost, associated to sensors and devices purchasing and implementation and maintenance of the related infrastructure [42]. In addition, costs associated with energy consumption.
- Environmental concerns, linked with the spread and dispersion of electronical components.

6.4.5. IoT-based SCA: classification

Table 9 shows all IoT-based automation initiatives found in the papers, classified on the base of which supply chain stage they work on. Those already described in detail in previous paragraphs will only be mentioned:

Table 9: IoT-based automation

SC stage	Reference	Process automated through IoT
Production	[27]	Collect plants data
	[15] [8]	Schedule maintenance. *Solution achieved thanks to integration with BDA*
	[43]	Monitor plants behaviour, detect anomalous conditions and recommend next. *Solution achieved thanks to integration with AI*
	[40]	Semi-automatic procurement. *Solution achieved thanks to integration with AI*
	[23]	Cloud based service-oriented Tool management (TM). *Solution achieved thanks to integration with AI, Cloud*
Transportation	[15] [31] [1] [14] [32] [42]	Track and trace shipments and trucks. *Solution achieved thanks to integration with Cloud*
	[31] [42]	Route planning and optimization. *Solution achieved thanks to integration with Cloud, AI*
	[27]	Route planning. *Solution achieved thanks to integration with AI*

Inventory	[33] [43] [42] [15]	Monitor warehouses and stock levels ([15] *Solution achieved thanks to integration with AI)*
	[42] [15]	Warehouse capacity optimization. *Solution achieved thanks to integration with BDA*
	[44]	IoT-based smart whs management system. *Solution achieved thanks to integration with AI*
Demand	[14]	Real time acquisition of market data, about customers, products, and interactions
All	[45]	Link and transfer data
	[1] [27] [15] [33] [25] [22] [21]	Resources, data, and process monitoring. *Solution achieved thanks to integration with Cloud*
	[31] [27] [14] [45] [42]	Data acquisition and readout
	[27] [42]	Make decisions. *Solution achieved thanks to integration with AI*

As for cloud technologies, these solutions are found both as stand-alone, and as part and support of more complex automation initiatives, carried out from integration of different technologies, mainly RPA and AI. In general, IoT and Cloud are much often presented together. At present, most of the servers of IoT are deployed in the cloud, providing various services at the application layer through cloud computing [15].

6.5. Blockchain

Among extant literature, research regarding the application of blockchain technology in supply chains is rather fragmented and diverse in topics [47]. Blockchain definition found in this regard are reported in Table 10:

Table 10: Blockchain definitions

Reference	Blockchain definition
[47]	"A consecutive list of time-stamped records (usually digital transaction data) sequentially linked using cryptography."
[29]	"Distributed, decentralized, digital ledgers supported by a network of multiple computers."

[32]	"Distributed ledger with confirmed blocks organized in an append only, sequential chain using cryptographic links"

Blockchain definition can be synthetize as: "Distributed, decentralized, digital ledgers sequentially linked using cryptography and supported by a network of multiple computers".

6.5.1. Blockchain technological structure

Main technological components of blockchain are the following [29]:

- Node: a computer with a copy of the blockchain data ledger, that is operated by a peer-to-peer network member in the blockchain environment.
- Transaction: a record containing data from a responsible owner who wishes to add that record to the blockchain in an immutable manner. Each transaction must be validated before its final integration into the blockchain. Data can be added to the blockchain manually or through RPA by scraping data from a transaction system as an ERP : after data are recorded to the blockchain and verified, they cannot be changed or removed [8].
- Block: a structured data compartment with data that belong to the block. Each block has a block header and a block body. The block header defines the current block and its hash value, the hash of the previous block, the timestamp and the block number. The block body defines the data structure that stores all the verified transactions in relation to the creation of a specific block.
- Consensus mechanism: a set of rules and procedures that enable network nodes reach a consensus and perform blockchain operations.

Decentralization refers to an operating mechanism that allows peer-to-peer (P2P) exchange or transactions without centralized authorities. This disruptive innovation eliminates the heavy reliance on third parties and intermediaries [47] [48].

Greater contribution of blockchain in supply chain automation is the automation of routine transactions through smart contracts [14] [8]. Smart contracts are defined as "a computerized transaction protocol that executes the terms of a contract". They automate execution of contract clauses and payment release [48]. They enable peers in the network to have full access and visibility to the history of all the smart contracts and transactions, as well as their current state. [32].

6.5.2. Reasons behind blockchain adoption in supply chain automation

Information communication technology (ICT) facilities are not able to avoid the possibility of unfair behaviour, and trust issues arising from different stakeholders using the data. Thanks to blockchain impossibility to modify or eliminate data once recorded and verified, and its absence of intermediaries, this technology came into play to overcome above mention problems, making data management system more secure, transparent, and reliable [29]**.** Allowing the security of the data, blockchain emerged as a potential alternative for enforcing traceability and transparency in supply chain transaction [48] and for enabling the creation of an automated, distributed, consensus-based, and immutable system for real-time monitoring and decision making [29].

Other main reasons behind blockchain based automation lies in the willingness of higher stakeholders' involvement and collaboration [33] [14].

6.5.3. Blockchain benefits

Companies implementing blockchain in SC showed the following benefits:

- Higher traceability of information, cash and process flows thanks to real-time visibility and monitoring of transactions [8] [47] [48] [29] [5].
- Eliminate a source of mistrust among stakeholders, thanks to reduced chance of data manipulation and fraud [8] [47] that facilities secure information sharing and data accountability [5] [48]. This also led to increase quality of decisions and negotiation with suppliers and stakeholders [33]
- Allows more streamlined business processes [47] and time reduction, thanks to intermediaries' elimination [48] [33]
- Drastic reduction of transaction and administrative costs [47] [48]

6.5.4. Blockchain challenges and limitations

Main issues when implementing blockchain in SCA scope are reported to be:

- Integration issues: blockchain needs to be integrated with other technologies and especially with many stakeholders and partners in the supply chain, presenting heterogeneous roles, demand, and level of IT infrastructures [47] [32] [22]. This issue is especially relevant for integration with IoT, for which the native Blockchain benefits of data privacy and immutability cannot be exploited. Also, smart contracts, that may facilitate obligation execution and process automation among parties, still requires a cross-disciplinary approach, combining technological, economic, and legitimation practices [47]

- Technical and legal concerns [47] [32]
- Blockchain is able to ensure that data are not manipulated but cannot ensure data quality. Errors linked with data entry in Blockchain cannot be corrected [32] [48]. A way to reduce this limitation is by automatizing data entry through RPA [8].
- Consensus issues may arise among actors regarding data ownership, storage and sharing [32] [48].
- High investment costs [32] and high costs due to great power consumption [47]
- Limitations on data storage capacity and scalability [47]
- Change management. Implementing blockchain to automate transactions and routine tasks means the need to profoundly change payment processes, tasks and roles [47]
- Security and privacy concerns, linked with the potential leakage of private sensitive data [47] [48] [32]

6.5.5. Blockchain based SCA: classification

Table 11 shows all Blockchain-based automation initiatives found in the papers, classified on the base of which supply chain stage they work on:

Table 11: Blockchain-based automation

SC stage	Reference	Process automated through blockchain
Procurement	[47] [32] [48] [8] [14] [33]	Transactions with suppliers through smart contracts
	[47]	Letter of credit
	[8] [27]	Trace flow of items from supplier for authenticity.
All	[14] [47]	Data sharing with stakeholders and automatic notifications
	[32] [33] [47]	Data and resources monitoring and tracking

6.6. Supply chain digital twins (SCDTs)

In 2019 and 2020, Gartner placed digital supply chain twins (SCDTs) in the top eight technology trends in the supply chain thanks to its possibility to innovate, optimize and improve supply chain, with particular emphasis on logistics systems, ensuring and approach for optimal and real time planning and controlling [4] [49]. In the current academic debate, digital supply chain twins do not have a consistent definition, given the broad range of feasible use cases [49]. The identified ones are reported in Table 12:

Table 12: Supply Chain Digital Twins definitions

Reference	Digital twins definition
[20]	"A dynamic simulation model that aggregates the available data in a structured way and allows simulations on the supply chain, including transport chains that are close to reality."
[3]	"Virtual supply chain replica that represents hundreds of assets, warehouses, logistics and material flows, and inventory positions. Using advanced analytics and artificial intelligence (AI), the digital twin simulates the supply chain's performance, including all the complexity that drives value loss and risks. It identifies where volatility and uncertainty exist, as well as where optimization is possible. A digital twin also enables scenario planning, so that a company can make decisions on the basis of business needs."
[49]	"A digital dynamic simulation model of a real-world logistics system, which features a long-term, bidirectional and timely datalink to that system. The logistics system in question may take the form of a whole value network or a subsystem thereof"

Digital supply chain twins' definition can be formulated as: "A dynamic simulation model which features a long-term, bidirectional, and timely datalink to the real supply chain system. It aggregates the available data in a structured way and allows simulations on the supply chain's performance, identifying where volatility and uncertainty exist, as well as where optimization is possible. It also enables scenario planning so that a company can make decisions based on business needs."

Application of Digital Twins in Supply chain management and Logistics, can be applied on four different levels [20]:

- SCDTs of a multi stakeholder value network.
- SCDTs of an internal supply chain, single stakeholder value network.
- SCDTs of a logistics site, such as a warehouse or a production site.
- DTs of a logistic assets, such as a truck or a forklift.

On the network level, both internal of multi stakeholders, two application areas may be identified [49]:

- Network management. It deals with management and supervision of value networks. Here SCDTs represents the whole value system including all relevant stakeholders and users are typically companies in the manufacturing industry with a globally distributed network.

- Transportation management. Transportation is part of network management and could therefore be included in the former category. However, this SCDTs don't describe the whole value system but just the relevant part for transportation purposes. Users of this area could be, for example, digital freight forwarding companies.

On the site level, three application areas can be identified:

- Manufacturing. Manufacturing is the area with by far the most use cases. It involves tasks which are related to the production of goods, like production planning and controlling or shopfloor management. A SCDTs represents a production facility, such as a manufacturing site, and users of this area might be production planners or factory managers.
- Warehousing. Warehousing includes tasks for warehouse management and material handling. The respective SCDTs represents a warehouse or distribution centre, and users of this area might be executives at these facilities.
- Cargo handling. Cargo handling takes place at sites which are logistics infrastructure, such as airports, ports or industrial parks. SCDTs indeed represents the site of interests and its throughput.

Each area is distinctive concerning the users, possible use cases and specific scope of the SCDTs. This consequently leads to different technological and processual requirements for each area [49].

6.6.1. Technological structure of SCDTs

SCDTs technology is represented by the model, the environment, and the engine of the simulation. To enable this and make it work, several synergistic technologies must be involved. These may vary on the base of specific use case and capabilities required by SCDTs implementation model [49]. Nevertheless, the following are identified as primary constituents of its technological structure:

- Modelling environment and engine technology: this represents the core of SCDTs, and the enabler of simulation capabilities.
- IoT. It allows things or objects to communicate with each over the internet. This communication and addressing allow physical objects to interact with each other without mandatory human intervention [20].
- 5G. For broadband cellular network [20].
- Cloud. To connect the platform to all data sources relevant to the digital twins modelling [3] [20]

- AI. To show human-like intelligent behaviours, which allow SCDTs to find solutions independently [20]. Machine Learning is the most used AI-based method for this purpose as well as inputs from advanced analytics methods. Open-source programming languages are required to develop the advanced analytics and AI models and interfaces needed [3].

6.6.2. Reasons behind SCDTs adoption

By simulating possible real-world scenarios in a digital world, the SCDTs can predict the best achievable outcome for the present and the future for the whole business ecosystem, make decision and carry out actions in the real world [49]. The new ways of exchanging and processing data make the digital twins technology a promising one for the automation of informational processes [4]. The data exchange between the supply chain and its SCDTs can be characterized by three attributes [49] [20]:

1. Bidirectional: Data are exchanged in both directions. Changes in the state of the logistics system therefore led to changes in the state of the digital model. Similarly, knowledge gained from the digital model leads to actions or decision-making in the logistics system. A certain degree of automation regarding the data exchange is explicitly not a prerequisite for a SCDTs.
2. Timely: Data exchange takes place in a timely manner.
3. Long-term: The data exchange and thus the lifetime of the SCDTs are designed for continuous, long-term use and not for one-time applications.

This results in end-to-end processes visibility and transparency, data driven insight and predictions generation, and above all the ability to simulate decision outcomes in advance, and therefore to improve SC control and performances.

In comparison with other commonly used digital systems, such as ERP and its components of TMS and SCM, digital supply chain shows advantages: the higher updated frequency, that is rarely real time in common information system, the advanced analytics capabilities it embeds and its simulation capabilities [20].

6.6.3. Benefits of SCDTs

Companies implementing SCDTs for SCA showed the following benefits:

- Full system control, thanks to end-to-end visibility and transparency [3] and consequent improve in resilience towards complexity and disruptions [3] [49].

- Enhanced data analysis and support in decision making, allowing to plan faster and more accurately, anticipate risks, reduce bottlenecks, and predict critical optimization decision. This leads to an overall efficiency improvement [3] [49]
- Cost reduction thanks to better resource planning and financial decisions. Inventory reductions can be up to 5%, thanks to better inventory synchronization with market demand. [3]
- Higher reaction speed, lower lead times, and increased system flexibility [49].
- Higher throughput and enhanced service level [3]

6.6.4. SCDTs challenges and barriers

Challenges encountered in SCDTs implementation are:

- Needed prerequisites of data quality and quantity [20]
- Difficulty in identify core business needs to address [3].
- Change management. Processes needs to be changed and re-adapted to effectively use the new insights and capabilities of SCDTs [3]
- High costs, variable depending on the set of capabilities and level of simulation model required. In any case, huge technological investments are needed. [49]

6.6.5. SCDTs based SCA: classification

Table 13 shows all Digital twins-based automation initiatives found in the papers. Impact of digital twins' automation is found to be systemic, so on several stages at once: therefore, automation will be described per each paper presenting it, rather than per stage.

Table 13: Digital twins- based automation

Reference	Process automated through SCDTs
[49]	Planning and monitoring of production, transportation and warehouses. Risk prediction, detection and management.
[3]	Cloud-based data platform connected to all data sources relevant to the digital twin modelling. Advanced analytics and AI models allow management to see anticipated risks in a fully integrated dashboard, such as warehouse congestion, to conduct in-depth analyses, and select among the mitigation actions proposed by the digital twin. It can also apply the insights to improve decision making, for example regarding inventory position, and alignment of sales plans with production capabilities.
[20]	Monitoring and simulation for predicting transportation times and determines logistic bottlenecks.
[21]	Predict bottlenecks in production

[12]	Inventory planning and optimization of inventory position inside the warehouse. Dynamic margin optimization.
[12] [4]	Risk detection, management, prediction

6.7. Cyber physical systems (CPS)

"CPS are systems of interconnected physical and computational objects, resulting in a close coupling of the cyber and physical contexts: assets and resources of the supply chain are integrated with computational components and can be monitored and controlled through computer-based algorithms" [28]. In this connected system, sensors, machines, workpieces, and IT systems are linked along the value chain beyond a single organization [25]. CPS are characterized by [50]:

- Interconnectedness: ability to act autonomously and automatically
- Intelligence

CPS information processing capabilities can have several levels [50]:

- Information acquisition: capability to acquire and share reliable data from different manufacturing resources.
- Information analysis: capability to derive meaningful information from the data through conscious perception and manipulation. Currently, CPS technologies largely focus on aspects of data collection and data analysis [50].
- Decision selection: capability to analyse information for decision-making purposes.
- Decision implementation: capability to process the feedback from the cyber to physical space, resulting in the implementation of that decision.
- Innovation: capability to innovate based on the acquired and analysed information.

CPS capabilities can also be differentiated on the base of the scope of operation addressed. Each scope is characterized by different reaction times and planning horizons [50]:

- Machine scope. Monitoring, supervising and controlling physical machines, with short reaction and planning time
- Production line scope. Monitoring and coordinating of the entire workflow and production execution. Reaction time is minutes, planning horizon amounts to hours/days.

- Factory scope. Developing and following-up on the achievement of long term plans. Reaction time is hours/days, and planning horizon addresses weeks.
- Supply chain scope.

6.7.1. Technological structure of CPS

CPS includes technologies for sensing and actuating, first Internet of things, coupled with wireless communication technologies, robotics, and AI-based computational power [50]. Even digital twins can be integrated as a part of a CPS [51].

6.7.2. Reasons behind CPS adoption

CPS allow the increasing integration of information and decision capabilities into industrial production and introduce new potentials for the planning, control, and the organization of supply chains [50]. CPS are envisioned to be the backbone of future industrial production, projected to be able to meet the changing customer requirements and increasing market competitiveness of the upcoming years [50].

6.7.3. CPS and SCDTs: a comparison

When looking at the manufacturing and production stage of supply chains, both CPS and DT are interesting technologies, that shows similarities as well as difference in their main scope [51].

They both include two parts: the physical and the cyber/digital part. The physical part senses and collects data, and executes decisions from the cyber/digital part, while the cyber/digital part analyses and processes data, on which then makes decisions. Core functions of both technologies is cyber-physical integration to gain control [51]. Through cyber–physical interaction and control, both enable precise and better management and operation of the physical world. However, some differences can be highlighted [51]:

- CPS consider sensors and actuators as its main module. Sensors and actuators are indeed necessary to interact with the physical world for data exchange, which is the most important feature of CPS, where intelligence is based on collected data. Through data management, processing, and analysis in the cyber world, control commands are generated. The results are feedback to the actuators, which execute operations according to the control commands in order to adapt to changes.

- DTs follow a model-based systems-engineering approach. DT core elements are models and data. Model are based on captured data but also integrate a whole pool of data to ensure consistency, such as business data, geometry, structure, material properties, rules, and processes. Models serve as a communication and recording mechanism to help interpret the behaviours of machines or systems and especially to predict their future state. Models therefore generate data and can learn and analyse their experience.

DT enables manufacturers to make more accurate predictions, rational decisions, and informed production. The combination of CPS and DTs would help manufacturers achieve more precise, better, and more efficient management [51].

6.7.4. CPS benefits

Companies implementing CPS for supply chain automation registered the following benefits: Increase production efficiency and processing time reduction [27], better decision making [27] [25]**, r**educe costs [25] and inventory levels [27], higher customer satisfaction [25] and enhanced transparency [25]

6.7.5. CPS challenges

Main challenges linked to CPS implementation are:

- Complexity and huge investment required [25]**.**
- Lack of skills to implement and efficiently exploit CPS capabilities [25]**.**
- Technical readiness related to the data management and infrastructures [25]**.**

6.7.6. CPS- based SCA: classification

Table 14 shows all CPS-based automation initiatives found in the papers, classified on the base of which supply chain stage they work on. As for Digital

Table 14: CPS-based automation

Reference	Process automated through CPS
[50]	Plan production, monitor execution, and negotiate appropriate reactions to adapt operations. It starts with information acquisition, which is subsequently analysed involving conscious perception and manipulation: this enables to notify in case of problems and share information. Following function is decision selection: it involves decision-making based on cognitive processing (ex: determine alternative plans to overcome a problem). The reached decision is then implemented.

[25]	CPS enables a smart factory. Machines can monitor and analyse the current processes, detect deviations and trigger the necessary adjustments as corrective action without human operators' involvement. In fact, AI enables the machines to learn from experience through their collected dataset and adjust to the new inputs from the surroundings, perform the human-like task and memorize the inputs for future optimization.
[27]	Data collection, storing and monitor.

7 Technologies potential for business processes automation

Chapter 6 described the key technologies for supply chain automation. Papers report and analyse several types of automation, from simple and local ones related to single tasks, to more complex and integrated ones. The purpose of this chapter is to deep dive into the relationships between technologies and their potential to automate the range of business processes that characterize the supply chain.

To do so, the processes have been grouped under some macro-categories:

- Data management. Processes involved with data capturing, storing, sharing, monitoring, updating and visualization. Their goal is to create, manage, and monitor the big dataset describing the supply chain. A further classification can be made, distinguishing processes for:
    - Data collection: processes focused on collecting, gathering, and storing data from the physical word into the digital one.
    - Data monitoring: processes focused on monitoring and keeping track of data and of their evolution in time. Their goal is to provide visibility and enable "active monitoring" for the detection of changes.
- Tasks execution. Processes focused on executing a certain digital task, following more or less structured rules. A further classification can be made:
    - Transactions execution: processes that deal with transferring, sharing, or sending data, documents, and money across systems, and across different actors of the supply chain.
    - Other tasks execution: this may be rule-based, as it happens in transaction automation, or non-rule-based. In the latter case, decision making and execution are performed, since automation does not arise from following a set of pre-defied rules, but rather from prior analysis and understanding of the situation, and how to react to it.
- Information delivery. Under this category fall all those processes focused on providing information and insights, starting from data manipulation. Their goal is to improve business performances and to support decision making.

Information delivered can be in the form of: recommendation systems or forecasts and predictions
- Planning and optimization. Under this category fall all those processes focused on scheduling, planning and dynamically optimize the plans. Automatic planning is defined as "the automatic generation of a plan to solve a problem within a particular domain" [16].

In the following paragraphs, all automation initiatives reported in Chapter 6 will be classified under these process categories. Complex automation, involving several steps and tasks and more than one technology, will be "broken into pieces" to better identify relationships between automation of single processes and enabling technologies.

7.1. Data management automation

Table 15 reports all data management automation. The results are graphically showed in Figure 5.

Table 15: Technologies for data management automation

SC stage	# papers	Technologies	Process automated	Process category
Procurement	2	Blockchain	Trace flow of items from supplier for authenticity.	Data monitoring
Production	1	IoT	Collect plants' data	Data collection
Production	1	AI, Cloud	Monitor plants behaviours	Data monitoring
Transportation	1	RPA	Track shipments	Data monitoring
Transportation	7	IoT, Cloud	Track and trace of shipments	Data monitoring
Inventory	1	IoT, Cloud	Warehouse and stock level monitoring	Data monitoring
Inventory	1	AI, IoT	Warehouse and stock level monitoring	Data monitoring
Inventory	3	IoT	Warehouse and stock level monitoring	Data monitoring
Inventory	1	AI, IoT	Warehouse monitoring	Data monitoring
Demand	1	IoT	Real time acquisition of market data, about customers, products, and interactions	Data collection
All	3	AI	Detect problems or changes in processes	Data monitoring
All	11	IoT, Cloud	Resources, data, and process monitoring	Data monitoring
All	9	IoT	Data acquisition and readout	Data collection
All	3	Blockchain	Data and resources monitoring and tracking	Data monitoring

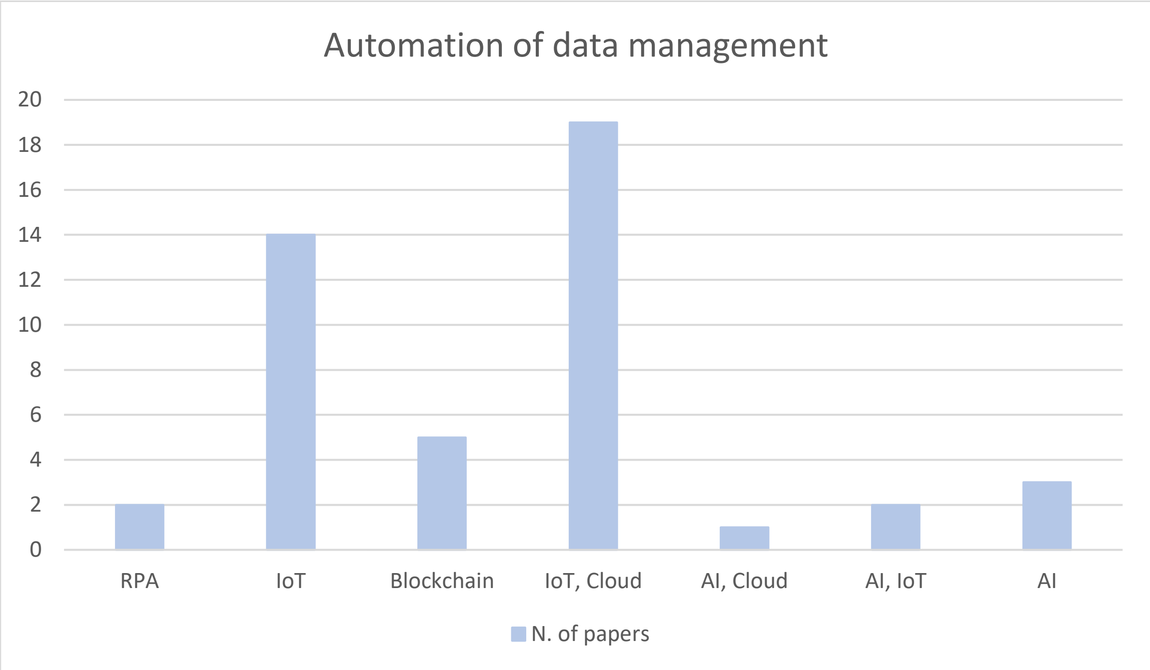

Figure 5: Technologies for data management automation

7.1.1. Data collection

IoT is the key technology used for data collection: it enables real-time automatic collection of data from potentially all links, nodes, and processes of the end-to-end supply chain, where availability of accurate and timely information is considered an asset for the company.

7.1.2. Data monitoring

IoT and Cloud computing are the most discussed technologies to enable automation of data, processes, and performance monitoring. Cloud is needed to ensure real time integration and visibility of all relevant data on the internet and therefore is an enabler of collaboration among partners, since they can use the same dataset. At present, most of the servers of IoT are deployed in the cloud, providing various services at the application layer [15]. Shipments tracking and tracing automation is the most discussed specific automation, enabled by IoT and Cloud. During transportation process several elements can be monitored, such as location and status of vehicles, status of the driver and of the cargo. Track and trace is especially needed in perishable food logistics where monitor of critical data can lead to avoid of food waste.

AI is present in several automation initiatives, supporting Cloud and IoT in plants and warehouses monitoring. Its key role as standalone technology lies in its ability to detect problems and changes in the monitored data, such as bottlenecks identification or achievement of a certain level of stock.

7.2. Task execution automation

Table 16 reports all data management automation initiatives. The results are graphically showed in Figure 6.

Table 16: Technologies for task execution automation

SC stage	#papers	Technologies	Process automated through RPA	Process category
Procurement	1	RPA	Placement of orders based on stock level	Decision execution
Procurement	1	AI, IoT	Placement of orders based on stock level	Decision execution
Procurement	2	RPA	Create order receipt invoices	Task execution
Procurement	1	RPA	Develop suppliers' performance scorecard	Task execution
Procurement	1	RPA	Process payments	Transaction
Procurement	1	RPA	Send requests for quotation to suppliers	Transaction
Procurement	1	RPA	Compare suppliers bid response based on predefined criteria	Task execution
Procurement	1	RPA	Place orders	Task execution
Procurement	1	RPA	Match orders, invoices and receiving documents invoices	Transaction
Procurement	1	RPA	Share documents with suppliers	Transaction
Procurement	3	RPA	Read, move and update suppliers' data on IT systems	Transaction
Procurement	1	AI, Cloud	Create electronics invoices	Task execution
Procurement	6	Blockchain	Transactions with suppliers through smart contracts	Transaction
Procurement	1	Blockchain	Letter of credit	Transaction
Production	1	RPA	Master data creation, maintenance, and transfer.	Task execution
Production	1	RPA	BOM creation.	Task execution
Production	1	IoT, Cloud	Automatic set-up of equipments	Task execution
Transportation	1	RPA	Enter information from documents to transportation management system (TMS)	Task execution
Inventory	1	RPA, Cloud	Enter customer order data in the warehouse management system (WMS).	Transaction

Demand	1	RPA, Cloud	Enter information from customer claims portal to supply chain quality portal	Transaction
Demand	1	RPA	Allocation of semi-finished products to customers on the base of dynamically adjustable criteria	Task execution
Demand	1	RPA	Enter and consolidate orders from multiple customers	Transaction
All	2	RPA	Data entry, transfer, and extract from ERP	Transaction
All	2	RPA	Automatic notification and alert	Task execution
All	1	AI, IoT, Cloud	Administrative tasks execution	Task execution
All	2	AI, IoT	Make decisions	Decision execution
All	10	Cloud	Update, transfer, and visualize data	Transaction
All	3	IoT	Link and transfer data	Transaction
All	2	Blockchain	Data sharing with stakeholders and automatic notifications	Transaction

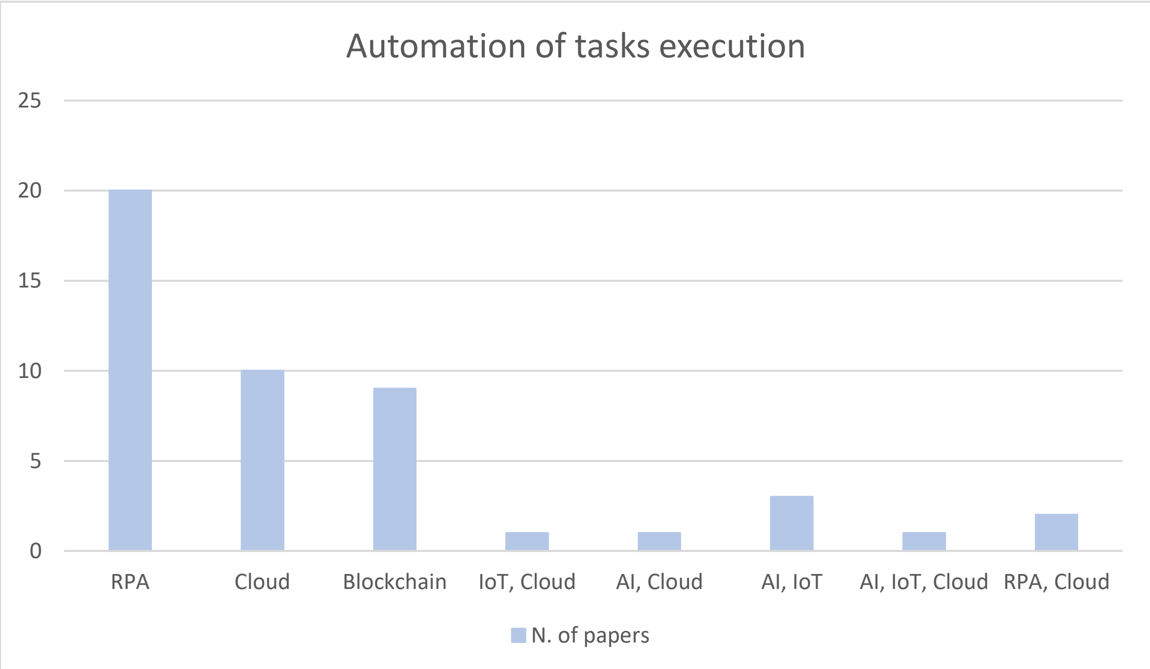

Figure 6: technologies for automation of tasks execution

7.2.1. Transaction automation

Automation of transaction is by far the most described type of task execution, and the reasons behind this lies in the fact that supply chains are full of data and documents shared among partners and moved among IT systems, for which manual transactions is linked with several problems, starting from data inaccuracy and data fragmentation.

Characteristics of this type of task, make of it a “perfect match” for **RPA** adoption: they are rule based, stable, with limited exception handling and repetitive. In addition, they are mature and executed in high volumes. Saiya et. al. states that it has been shown that transactional tasks, long and high-volume processes are the ones where implementation of RPA can register the amplified benefits, and in fact is the most studied technology for this category [36]. Given from one hand the high diffusion of RPA and its ease of implementation, and on the other hand the high volume of transaction tasks in supply chain, lot of them have been automated and studied. RPA benefits of reduction of tasks execution time is particularly visible when dealing with automatic data entry and transactions, moving away from manual insertion of data in excel sheets. In some cases, the automation of data transfer has been described through integration of RPA and Cloud, since very often information systems are cloud-based, and transactions happen in a Cloud environment.

The other technology that appears to be a good match for this type of task automation, is **blockchain**. Its application is linked with sharing economic and financial documents, first smart contracts, described by majority of papers involving Blockchain. It is in these types of sensible documents indeed, that Blockchain benefits of reduced chance of data manipulation and fraud, and complete information traceability, are most valuable and desired.

Cloud itself is also one of the most valuable technologies to automate transfer of data among different information systems of the company, given its collaborative nature: automation of data transfer through cloud is the most described automation. Cloud-based ERP systems are often implemented to address the common problem of disparate ERP systems within organizations [8], linked with high necessity to transfer and send data.

Procurement is by far the stage of supply chain where majority of tasks executions are automated. The reason why procurement is well suited for this type of automation is the continuously growing number of **transactions** with suppliers that involve a large amount of information processing and communication. Not only transactions are widely presents in this stage, and therefore represents a good automation material, but their automation is valuable to address the issue of interoperability of systems, often reported in procurement management. Automation of data transactions indeed provide real time integration of information and communication, enhancing collaboration. Also financial transactions enabled by Blockchain find their main application in this stage, where relationships with suppliers are managed.

7.2.2. Other tasks execution

RPA is the preferred technology even in this case. Most relevant examples are the automatic creation of suppliers' invoices and automatic send of notification or alert when a problem is encountered. In all these cases automation is performed thanks to RPA ability to execute a series of rules and constraint given and predefined in advance.

Some initiatives describe execution of tasks that arise from a prior analysis of the situation that led to identification of a decision, that is indeed implemented. The few examples found are mainly AI based.

7.3. Information delivery automation

Table 17 reports all data management automation. The results are graphically showed in Figure 7:

Table 17: Technologies for information delivery

SC stage	# papers	Technologies	Process automated through RPA	Process cat
Procurement	1	AI, Cloud	Provide sourcing recommendation	Recommendation
Production	1	AI	Packaging recommendation	Recommendation
Production	6	AI	Predictive maintenance	Prediction
Production	1	BDA	Predictive maintenance	Prediction
Production	1	AI, Cloud, IoT	Predict breakdowns	Prediction
Production	1	AI	Bottlenecks prediction	Prediction
Production	1	AI, Cloud	Resource planning.	Prediction
Production	1	AI, Cloud	Detect anomalous conditions in equipment	Prediction
Production	1	AI, Cloud	Recommend next steps	Recommendation
Inventory	1	AI	Shortage prediction	Prediction
Inventory	1	AI	Predict delivery times	Prediction
Demand	6	AI	Demand forecast	Prediction
Demand	2	BDA	Demand forecast	Prediction
Demand	1	AI	Price forecast	Prediction
Demand	1	AI	Predict customers behaviours	Prediction
All	1	AI, IoT, Cloud	Recommendation for decision making	Recommendation
All	1	BDA	Risk prediction	Prediction
All	1	BDA	Propose recommendations and adjustments through real time feedback	Recommendation
All	1	AI	Provide recommendations about potential business partners (ML)	Recommendation

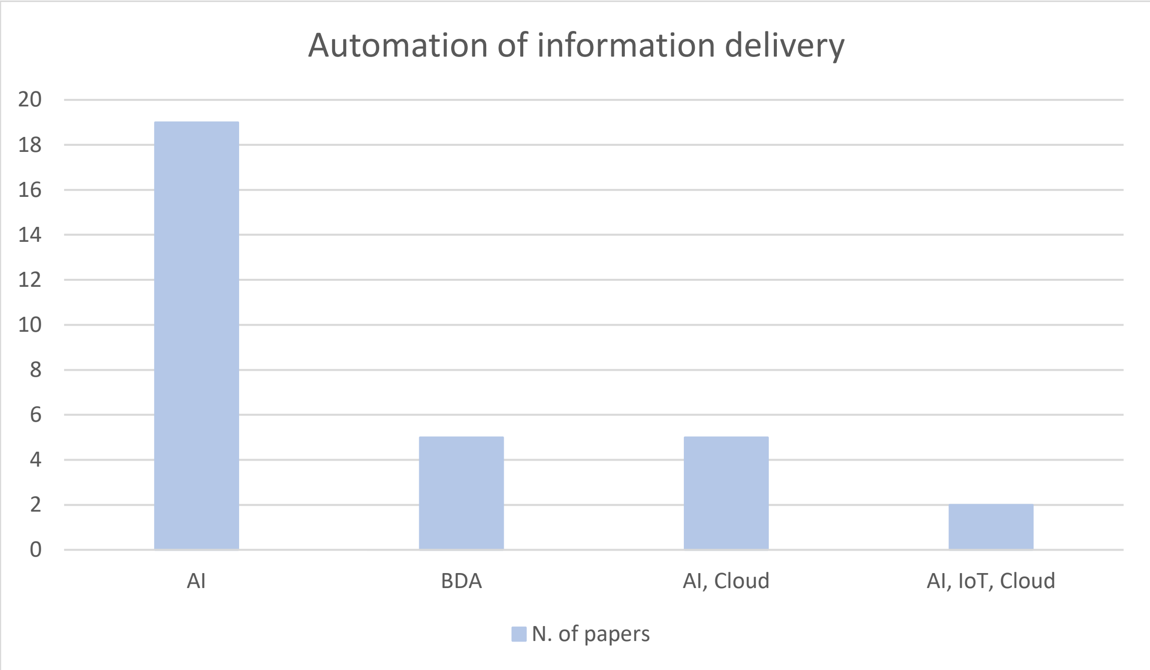

Figure 7: Technologies for automation of information delivery

The results show a pretty clear situation: **AI** is necessary when cognitive capabilities and human-like intelligence is required, as well as BDA. Indeed, its ability to process unstructured data and automate tasks requiring human intelligence or judgement make it the number one choice in these cases. To deliver this information, prior automation of data collection and monitor is a must, to have complete, reliable, extent and real-time data set on which to work on.

7.3.1. Recommendation systems

Artificial intelligence is the major enabler of recommendation automation with predominance of Machine Learning. Its integration with **Cloud** also appears relevant, and its specified in half of the category automation. Its role is to provide the required integrated database on which to perform analysis to deliver recommendation. Majority of automated recommendations deal with how to react to problems or changes detected during data monitoring process. These types of solutions are the necessary automation step in between active monitoring ones and decision execution automation.

7.3.2. Predictions and forecasts

AI-based predictive tools enable the supply chain to avoid major disruptions. Key automation that papers point out are predictive maintenance and demand forecast.

Predictive maintenance is often automated through ML: the status of equipment is remotely evaluated, offering insights about probability, timeframe and nature of issues, and actions such as scheduled replacement of parts and maintenance operations are generated. It results especially needed in large and complicated systems, that are made up of massive machines, for which predictive maintenance automation is linked with most efficient resource uses, higher output, increased supply chain reliability and lower operational costs [11].

Automation of demand forecast is of strong interests, since reduction of the uncertainty and variability that is always associated with demand is one of the major automation goals, especially when customer behaviours changes.

7.4. Planning

Table 18 reports all data management automation. The results are graphically showed in Figure 8.

Table 18: Technologies for planning automation

SC stage	# papers	Tech	Process automated through RPA	Process cat
Production	1	RPA	Production scheduling	Planning
Production	2	AI, Cloud	Schedule maintenance	Planning
Production	2	AI	Schedule production	Planning
Production	3	AI, Cloud	Agile production planning	Planning
Transportation	1	RPA, AI	Route optimization.	Planning
Transportation	1	RPA	Schedule shipments	Planning
Transportation	3	AI	Route planning	Planning
Transportation	2	AI, IoT	Route planning	Planning
Transportation	1	AI, IoT, Cloud	Route planning	Planning
Transportation	1	BDA	Distribution network planning (BDA)	Planning
Transportation	3	AI	Dynamic route optimization	Planning
Transportation	1	AI, IoT	Dynamic route optimization	Planning
Transportation	1	AI, IoT, Cloud	Dynamic route optimization	Planning
Inventory	1	AI	Schedule the picking process (ML)	Planning
Inventory	2	BDA, IoT	Warehouse capacity optimization	Planning
Demand	3	AI	Demand planning	Planning

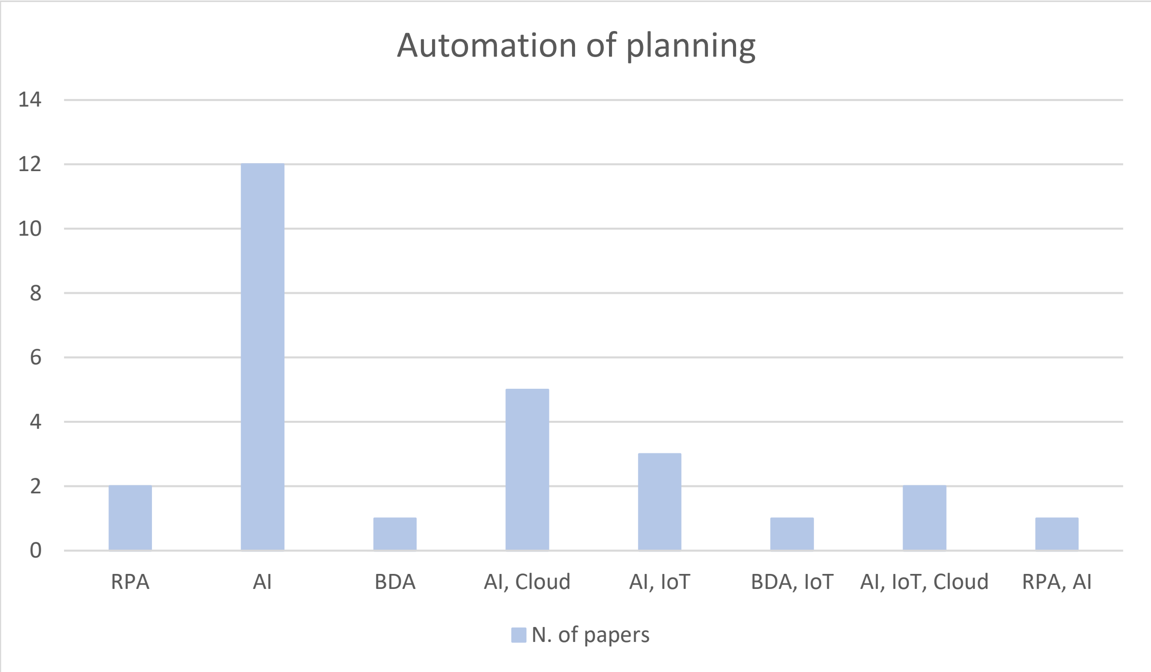

Figure 8: Technologies for planning automation

"Automated Planning is concerned with the automatic generation of a plan to solve a problem within a particular domain. At its simplest, a plan is a sequence of actions. Given an initial state, the planner tries to find the actions such that their ordered execution from the initial state achieves some goal conditions." [16]. Automated planning is achieved through fully automated technologies platforms that can reach optimization on a global level rather than on a local one. The final goal of planning automation is process orchestration, meaning having a single, comprehensive system that includes the entire supply chain.

AI is required since cognitive capabilities are needed in planning automation, specifically in the extent required to recognize patterns and categories, deal with high volume of complex inputs coming from large range of sources. Rodiguez at. al. identifies in demand planning the major application of AI in supply chain automation, together with demand forecasting [38]. Major AI-based automation is route planning and dynamic route optimization, for which the roles of IoT and Cloud are also relevant. Other relevant ones include demand planning, warehouse capacity optimization, as well as production scheduling.

Cloud is often described together with AI: real-time data availability and visibility provided by cloud computing indeed, make of this technology one of the main enablers of planning and scheduling activities [27].

RPA-based automation are for scheduling purposes.

Majority of automation are described in the transportation stage. In logistics, strong focus is given to route planning and optimization. Distribution network planning automation is also described, showing the importance of optimizing transportation and network configuration, especially in global and complex supply chains. Lu et. at. describes the game-changing role of AI techniques in transportation planning automation, such as firefly algorithm [31].

7.5. Technological overview

A recap of the results obtained is visually showed in Figure 9, where the potential of each combination technology – business process automation is highlighted.

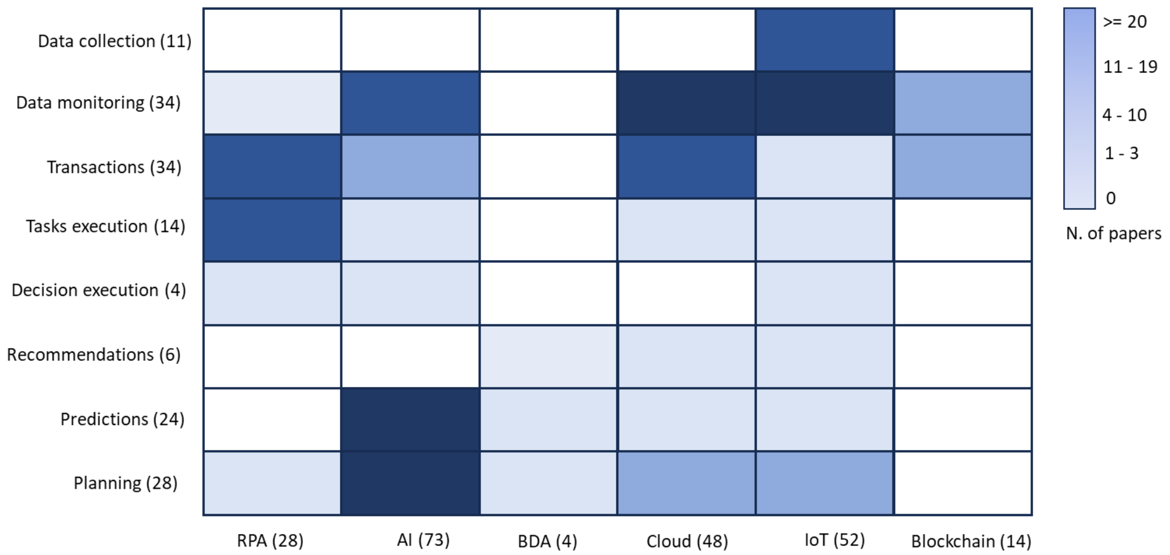

Figure 9: Heatmap of technologies enabling business process automation per number of papers describing them.

Artificial intelligence finds perfect application for planning and predictions automation. Thanks to its capabilities of patterns and category recognition, logical reasoning and problem-solving, AI provides novel and superior possibility to automatically plan and predict. Insights, and results deliverable go far beyond ones linked to traditional methods and allow a real upgrade of supply chain performance.

Data monitoring automation through **IoT and Cloud** is also among the most interesting aspects of SCA, thanks to the integrated, shared, complete and updated dataset that they can create. Data monitoring automation is relevant to provide visibility, reactivity, risk detection and collaboration. These representing also fundamental enabler of planning and decision-making automation, and for this reason Cloud and IoT are often cited also in these scopes. Other good combinations are:

- Automation of transactions and tasks execution through RPA. RPA finds a perfect fit for automation of routine, repetitive and standard tasks, abundantly presents all over supply chains, especially in procurement. Its relatively easy and cheap implementation process in comparison with other technologies, abundancy of vendors in the market, clear and measurable achievable benefits, make of RPA the first step of many companies toward automation, and the most diffused technology for tasks execution and transaction automation.
- Data integration and information transactions among systems through Cloud. Cloud-based ERP systems are often implemented to address the common problem of disparate ERP systems within organizations [8]: given its collaborative nature, it enables automatic sharing and transferring of data.
- Data collection through IoT.
- Data monitoring through AI, enabler of "active monitoring", for detection of changes and problems in the monitored data.

Blockchain-based automation is relevant for automation of transactions and their traceability when strict conditions related to data security and trust needs to be meet. The specificity of its applications, and also its complexity, explains why fewer articles discuss blockchain based automation in comparison to other technologies.

The most discussed automation initiatives are showed in Table 19:

Table 19: most discussed SCA

Reference	# of papers	Technology	Process	Process category
[5] [30] [36] [38] [29] [27] [26] [13] [42] [43] [12]	11	Cloud, IoT	Resources, data, and process monitoring	Data monitoring
[36] [42] [30] [5] [43] [6] [26] [13] [16] [25]	10	Cloud	Update, transfer, and visualize data	Transaction
[42] [30] [16] [46] [12] [44] [25] [39] [13]	9	IoT	Data acquisition and readout	Data collection
[13] [36] [42] [5] [16] [43] [12]	7	IoT, Cloud	Track and trace of shipments	Data monitoring
[49] [43] [14] [6] [16] [38]	6	Blockchain	Transactions with suppliers through smart contracts	Transaction
[40] [26] [11] [12] [24] [13]	6	AI	Predictive maintenance	Prediction
[6] [18] [16] [11] [24] [30]	6	AI	Demand forecast	Prediction

8 Toward an automated supply chain

Potential of single technologies for automation of different business processes has been highlighted by Chapter 7. Nevertheless, automation potential does not lie in a single technology but rather in an ever-increasing range of technologies, tools and techniques that need to work in concert with one another, to increase automation volume and potential and expand automation scope [1]. In this context, it is relevant to analyse which papers show SCA that goes beyond single and specific processes and leads to the orchestration of several automated ones. This enlarges the automation scope and its impact on the supply chain, that goes from local to systemic.

The scope of the analysis is to identify the current technological readiness toward the final goal of building an automated supply chain. In automated supply chains the entire end-to-end flow, from procurement, production, transportation and logistics, inventory, delivery, and demand management is automated, with data, decisions and execution integrated across all stages and actors. Actions are taken for the optimization of the entire supply chain eco-system, rather than of local functions.

In the following paragraphs such automation initiatives will be described, deep diving into their technological side, impact on SC management, as well as implementation challenges.

8.1. Integrated automation

All integrated automation initiatives are numbered and described in Table 20:

Table 20: Integrated automation

Classification	Reference	Automation	Technologies
1	[6]	Procure to pay process: RPA creates and sends requests for quotations, then compare supplier bid responses to predetermined criteria. It then creates purchase orders and match them with invoices and receiving documents. It finally processes payments.	RPA
2	[6]	Cloud-based procure to pay system to automate the entire process.	Cloud, RPA
3	[22]	Purchase to pay process, automated for 50%	RPA, AI

4	[35]	Allocation of lots to customers and scheduling of their production. The system works in real-time (utilizing the existing Real Time Dispatcher repository) and assigns lots to customer orders based on a set of weighted criteria that is dynamically adjustable to the needs of the supply chain companies. After allocation, the lot starts are scheduled and equally distributed over the weekly time axis.	RPA
5	[9]	BOM generation. RPA open the Green Supply Chain Management (GSCM) under assigned ID and download material master from the system. It then login to SAP and download the second material list. Next the robot matches material data between two downloaded sheets and generates final version of shortage components to upload on SAP. Any not-found issue will be recorded and reported for easier tracking and solving actions. If issues like mismatching of material master still occur, due to disconnections between systems, RPA will send an alert for mismatch errors to system users. The human employees then can focus on dealing with only these errors and carry out corrective actions to ensure better data synchronization the following time.	RPA
6	[32]	Customer claims handling process. RPA read the customer claim in respect to a vendor code automatically, from the customer portal in the moment a customer updated the data. RPA picks the information and update them in an Integrated Supply Chain Quality portal (ISCQ) which is exclusive for the organization. ISCQ sends the communication to respective stakeholders and wait for immediate response. If the immediate response is not updated, RPA send the escalation to management with warning notification. In case of repeat claims it goes back to the product directory and searches for similar product and process and give the trigger to process owner for horizontal deployment. If the same failure mode was not captured in PFMEA (Process Failure Mode Effect Analysis) it will also send the trigger to process design engineer to update it.	RPA, Cloud
7	[39]	Semi-automatic procurement of wooden OEM parts for specialist instruments/tools. The process is triggered by an autonomous agent when the storage's stock of a specific production input part is low i.e., below a specified threshold. To detect this, the agent can rely on a set of IoT sensors (cameras). It registers the bid specification with a business process execution engine (the specification triggers the process). The bid specification is then reviewed and possibly enhanced by a human. Subsequently, the process execution engine starts a loop that automatically	AI, IoT

		updates the bid specification based on the latest sensor data from storage and production environment, and then registers bids for the to-be-procured good with an external broker agent. If the sensors register an anomaly in the production line environment, the agent interprets the received data to assess whether the bidding should be stopped. If so, the process is terminated.	
8	[3]	Digital twins with a Cloud-based data platform to connect all relevant data sources. It uses open-source programming languages to develop the advanced analytics and AI models, as well as the interface for end-user access to the analytics insights. Management is now able to see anticipated risks in a fully integrated dashboard, conduct in-depth analyses, and select among the mitigation actions proposed by the digital twins. It can anticipate risks, for example warehouse congestion, 12 weeks in advance and take steps to avoid asset standstills. It can also apply the insights to improve decision making, such as in determining which assets to upgrade so that it can better manage its increasingly complex order book and in deciding how to better align its sales plans with the capabilities of its asset network.	SCDTs embedding Cloud and AI
9	[16]	Electronic procurement. The buyer firms implementing a Web-based e-procurement system for conducting purchasing activities can be supported in daily business and administrative tasks, as well as in complex decision-making processes. Artificial Intelligence, Big Data, and the Internet of Things are core elements to automatize these operative activities and create space for more strategic initiatives driven by a human. Cloud computing and Data Analytics play a critical role in terms of information acquisition, storage and elaboration.	AI, BDA, IoT, Cloud
10	[29]	CPS for Smart factory. Machines are able to monitor and analyse the current process, detect the deviation, and trigger the necessary adjustments as corrective action without human operators' involvement. In fact, AI technology enables the machines to learn from experience through their collected dataset and adjust to the new inputs from the surroundings, perform the human-like task and memorize the inputs for future optimization	CPS embedding IoT, Cloud, AI, BDA
11	[13]	Cloud based service-oriented tool management (TM). Through a unique and standardized identification scheme based on serialized numbers, all relevant tool data are captured and stored in remote storage location utilizing cloud computing. The overlying service layer has access to the stored data and exposes the functionality realized for the TM system for supporting an efficient collaboration	IoT, Cloud, AI

		between parties involved. Two basic kinds of services are developed: core business services for generating, calling, updating, and visualising all tool relevant data and perform automatic set-up on the base of respective set-up parameters; and value-added services that comprise additional and more complex functionality, such as tracking and tracing, inventory, condition and maintenance management as well as the communication with other information and control systems. In addition, analytic methods are applied to realize services like tool usage prognosis, fault prediction and service planning.	
12	[44]	IoT-based smart warehouse management system. IoT capture data and several algorithms perform task optimization on the base of data, such as adaptive task planning and path planning algorithms for the picking process. Final goal is improvement of the overall flow of the supply chain.	IoT, AI
13	[25]	Digital twins for monitoring multimodal supply chain and perform simulation to predict delivery times and determines logistic bottlenecks	SCDTs embedding IoT, Cloud, AI
14	[50]	CPS to plan production, monitor execution, and negotiate appropriate reactions to adapt operations. Information are sensed and registered, and subsequently analysed involving conscious perception and manipulation. This enables to notify in case of problems. Decision-making based on cognitive processing is also performed i.e., determine alternative plans to overcome a problem. The reached decision then leads to the implementation of responses/actions	CPS based on IoT and Cloud

To assess their potential in the direction of building an automated supply chain, they have been classified on two axes:

- Automation completeness. Assesses the level of required human intervention to perform automation.
- Impact on SC. It can be:
  - At local level: automation impact an integrated set of processes.
  - At stage level: automation impact is over an entire stage of the supply chain, such as automation of the whole procurement management or of an entire production plant.
  - At network level: automation impact several stages, systems, and functions in an orchestrated way.

Table 21 reports these results, together with implementation challenges, if described.

Table 21: Analysis on integrated automation

Classification	Completeness	Impact	Implementation challenges registered
1	Complete	Local	-
2	Complete	Local	-
3	Partial, automated for 50%	Local	Lack of clear strategy and roadmap for the automation of procurement process.
4	Complete	Local	-
5	Partial, human intervention for exception handling	Local	Synchronization between separate systems. Data simplification prior implementation phase
6	Partial, human intervention for exception handling	Local	-
7	Partial, humans for review and enhancement	Stage level – procurement management	-
8	Partial, human for decision selection and implementation	Network level	Challenges to identify core business needs to address with SCA. Change management
9	Partial, humans for strategic decisions	Stage level - procurement management	Security concerns of transactions Lack of skills and knowledge, as well as of IT infrastructure Interoperability issues Company culture and need of management support: industry related.
10	Complete	Stage level - production management	Lack of skills, given the high complexity to manage. Huge investments Data management and IT infrastructure readiness

11	Partial, human for decision execution.	Stage level - production management	Horizontal integration Heterogeneous IT infrastructure Need to develop a new suitable business model
12	Complete	Local	-
13	Complete	Local	Integration of the different technologies Data quality and availability prerequisite.
14	Complete	Stage level - production management	-

Majority of reported applications have a local impact, and are primarily based on RPA, programmed to execute, and manage the sequence of required actions. These are mainly partially automated, since human intervention is required for exception handling, or for triggering the process or for decision-making.

Complete local-impact automation found are based on AI, often working through Cloud platforms, that integrates the above-mentioned capabilities.

At stage level, attention is put toward procurement and production management automation. Procurement automation embed AI, BDA, IoT and Cloud to enable decision making, in addition to tasks execution. However, human intervention is still required to review and enhance the process and to implement strategic decision in the stage. [16] underlines how "Based on finding, it can be concluded that there is yet no single system or application that can support the execution of all the functions in the procurement process, and that the issue of interoperability of systems, particularly in cloud environments and e-market platforms remains a challenge in the use of industry 4.0 technologies to procurement activities."

Other stage- automation initiatives are focused on production and mainly enabled by **CPS** application. These are complete, enabling automation from data capture to monitoring, to decision making and execution. CPS can indeed capture data from plants relying on IoT and integrate them in the collaborative Cloud environment. Relying on cognitive capabilities, it can monitor and control assets and resources with superior performances, automatically understanding and notifying when a change in data happen, such as a problem in production. CPS can also negotiate appropriate reaction to adapt operations based on cognitive processing and implement them. CPS are envisioned to overcome static automation to feature adaptive automation that dynamically allocates tasks between humans and machines based on the cognitive and physical demands of the user. Waschull et. al. states that CPS introduce new potentials for the planning, control, and organization of production processes, and can be a game changer in this supply chain stage [50].

The only automation reported that extends its impact across multiple stages and functions is described by [3]. It describes a **Supply chain digital twins'** automation able to capture data and use them to simulate the whole network. Power of digital twins lies in its ability to aggregate data of all assets and nodes of the supply chain in a structured way, allowing full system monitoring, control, visibility, and transparency, as well as problems detections and recommendation for reactions, such as presence of bottlenecks in production or achievement of a certain stock level in warehouses. Trough simulations, it is possible to identify where volatility and uncertainty exist, as well as where optimization is possible This enables data analysis, risk prediction, risk mitigation, decision making and planning in an orchestrated way. Digital twins offer a completely new way for planning: thanks to real-time exchanging and processing of data from the physical world, and its possibility to simulate and evaluate opportunities on a digital platform, it enables scenario planning on the base of the business needs. Optimal planning is reached with loss minimization and strong alignment and synchronization of different plans across the network. Even given the relevance of SCDTs for reaching automation on a network level, it still requires human intervention for complete decision implementation and execution in the described application.

8.2. Readiness evaluation

What arises from the analysis is that the journey toward building an automated supply chain is still long, given the predominance of local-impact automation over stage and especially network ones, and of partial over complete ones, as showed in Figure 12.

Barriers reported by papers in implementation of these integrated automation, and that may prevent more comprehensive ones are reported in Figure 13**Error! Reference source not found.**. Integration problems among technologies and systems that needs to work together appear as the most relevant, together with organizational readiness: companies require a clear strategy, business model and roadmap for implementation, as well as leadership support to manage the change. Other relevant barriers, that highlight the long journey toward an automated supply chain are lack of IT readiness, skills, and knowledge to implement, manage and exploit technologies for automation. Barriers of data requirements, shows the relevance of automation of data acquisition, integration and monitoring early in the automation journey.

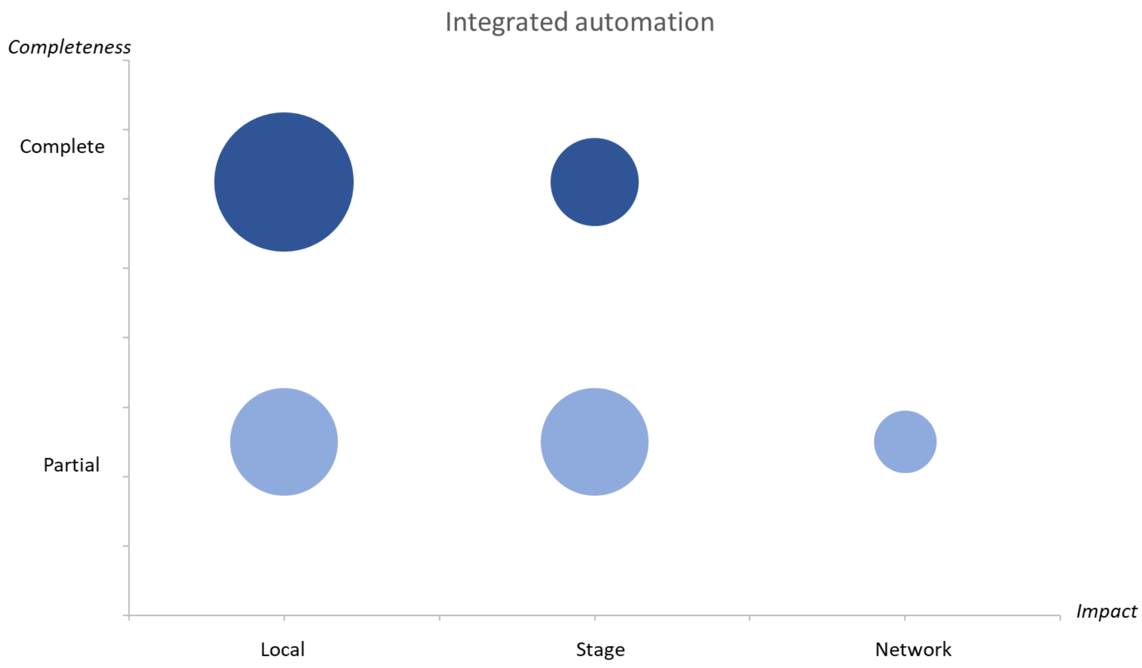

Figure 10: Integrated automation per impact and completeness level

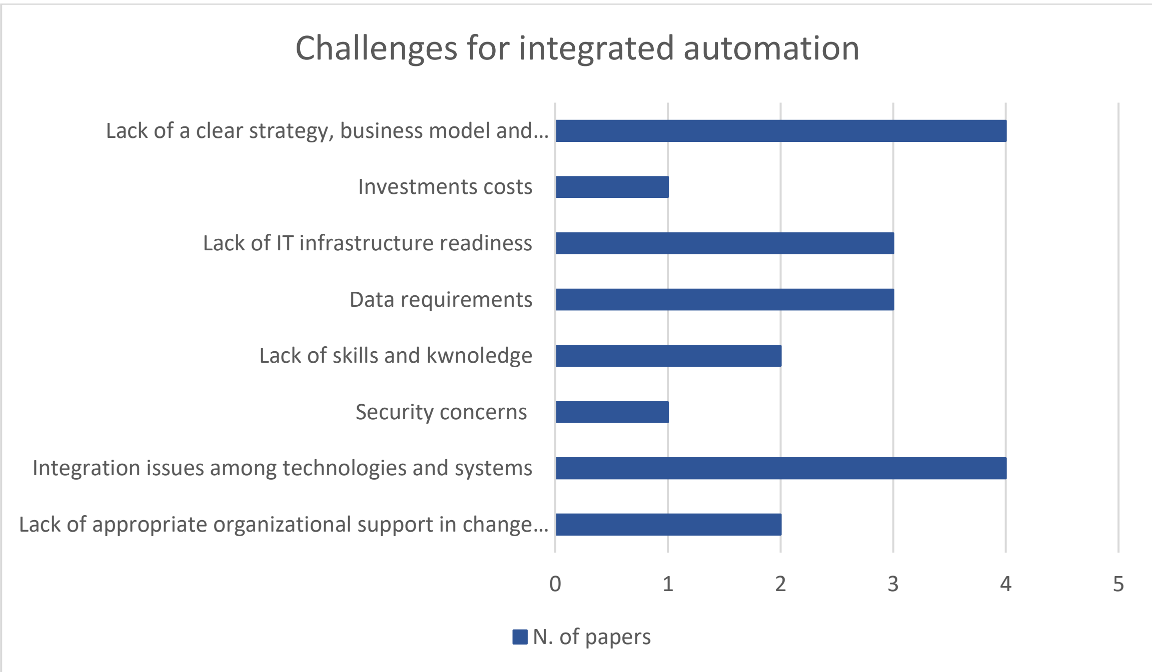

Figure 11: Challenges of integrated automation

Digital twins' superior capabilities are relevant for reaching an automated supply chain, even if it still requires human intervention for selecting among recommended scenarios and implementing more complex decisions. An interesting configuration could be the integration of SCDTs into CPS, to exploit both the former simulation and planning capabilities and the latter sensing and decision actuating ones, that could be extended also outside the production sites. In this context however, it is relevant to underline additional barriers linked with these technologies' adoption: high implementation complexity and related huge investments costs.

9 Managerial implications for implementation roadmap

This chapter aims to analyse several dimensions that may be relevant for companies to assess the best way to approach automation, and therefore define an implementation roadmap. The variables considered are:

- Implementation challenges. Key challenges in implementation of each technology for SCA are analysed and compared, to identify which are easier to be implemented sooner in the automation journey and which will require higher experience, readiness, or investments.
- Relevance of benefits. Analysis of key benefits arising from different technological automation are analysed and compare, to identify which may led to greatest positive impact on supply chain performances.
- Relevance for integrated automation. Presence of technologies in integrated automation is analysed, to understand which are more needed and relevant in the direction of building an autonomous supply chain.

9.1. Implementation challenges

Figure 12 describes technologies' challenges per number of mentions in papers.

Lack of a clear vision, resistance to change and integration between technologies and systems, are the most discussed challenges of SCA. This is in line with major challenges identified for integrated automation.

- Advanced analytics seems to be the most complex technology to implement, considering challenges such as difficulty to reach the needed skills to effectively implement and use the technology, availability and quality of data, integration, privacy and security concerns. It is important to underline the fact that some technologies, such as AI, are discussed by a much wider number of papers in comparison to others, leading to apparently higher relevance of their implementation challenges.
- RPA also shows challenges, but mainly related to organization and company mindset, rather than on the complexity of the technology itself. RPA is indeed easy to introduce in the company, due to limited training and coding skills

necessary to use it, and to the fact that works "on top" existing information systems, without integration problems or need to change the existing processes workflow. In addition, it is a mature technology and availability of providers in the market is huge.

- Cloud appears to be the "easier" technology to implement for SCA.

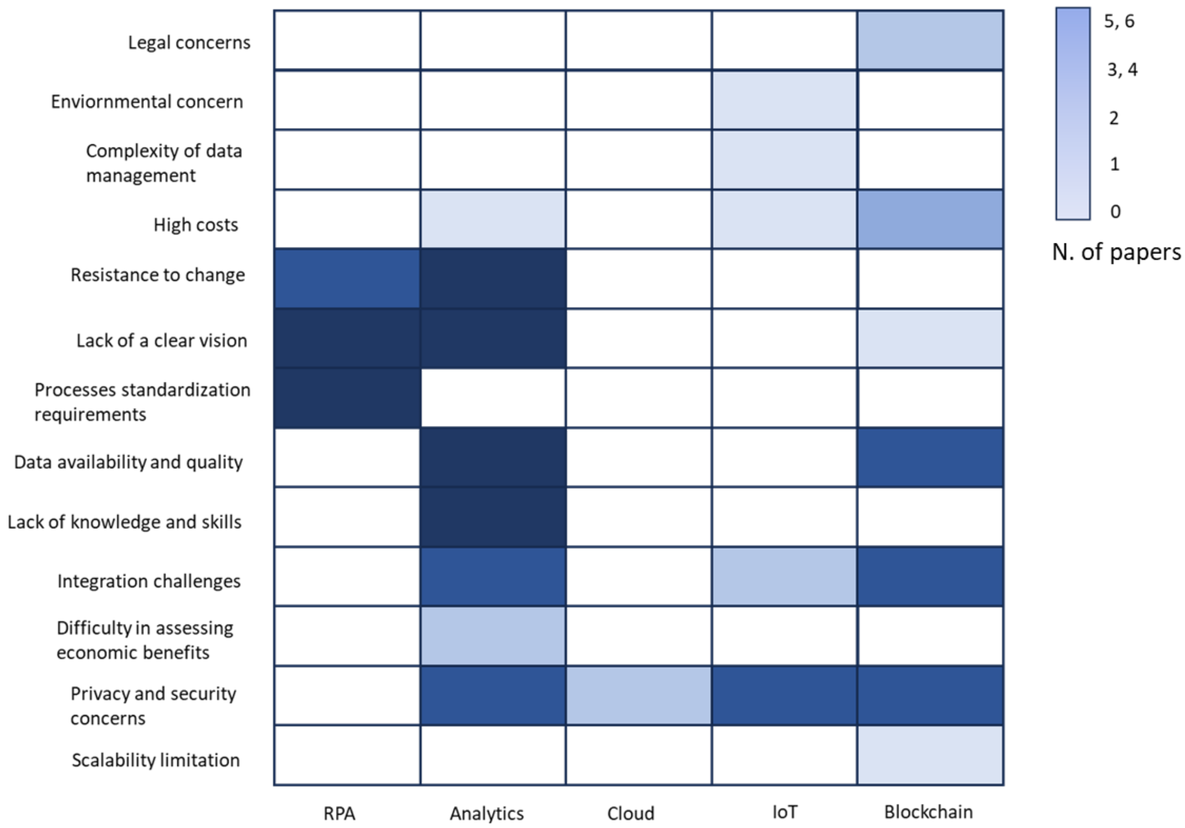

Figure 12: Implementation challenges of different technologies, per number of papers mentioning them.

By comparing results of paragraphs 7.5, 8.2 and 9.1, it emerges that AI is the most discussed technology for SCA, but also the most challenging one to implement, and one of the major barriers of AI-implementation lies in lack of availability and quality of data. In this context, IoT and Cloud implementation to automate data capture, integration and monitoring, seems to be a pre-requisite for ensuring success of AI-based automation, as well as more complex ones. This is supported by the fact that IoT and Cloud are indeed very often described as primary enabler of planning and information delivery automation. Data quality and completeness level can also be improved through RPA-based transactions automation.

9.2. Relevance of benefits

Figure 13 shows relevance of technologies-based benefits:

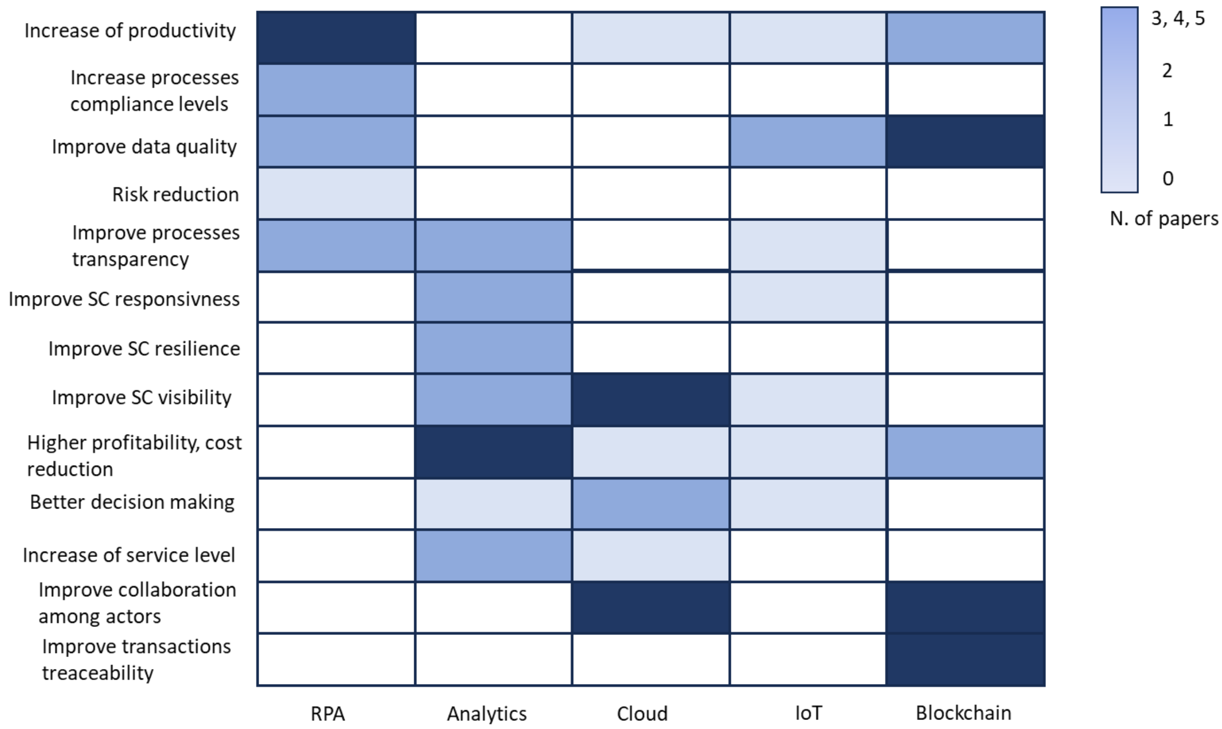

Figure 13: Heatmap of benefits of different technologies-based automation, per number of papers mentioning them.

Some comments and conclusions drafted from the analysis:

- Majority of benefits given by RPA are process- and data-related. Even if they clearly also impact the overall SC performances, they are mainly local. Indeed, RPA major application is for automation of single tasks.
- Analytics- and cloud-based automation are the ones showing greater global benefits, with particular focus on supply chain visibility, profitability, and stakeholders' collaboration.
- Blockchain benefits have been deeply discussed by literature, given its unique approach to enhance security and traceability of data and transactions, increasing trust among actors, through smart contracts.

9.3. Presence in integrated automation

Figure 14 shows presence of single technologies in integrated automation, from which some reflections can be made:

- Lack of cognitive capability and data analysis leave RPA impact on SCA at local level, and very often human intervention is needed. Few integrations of RPA with other technologies have been found.
- Analytics, Cloud and IoT integration is the main enabler of more complex automation. They are also the key components of both CPS and SCDTs, technologies showing the greater capabilities at stage and network level.
- Blockchain integration with other technologies is not relevant in the scope of an automated supply chain.

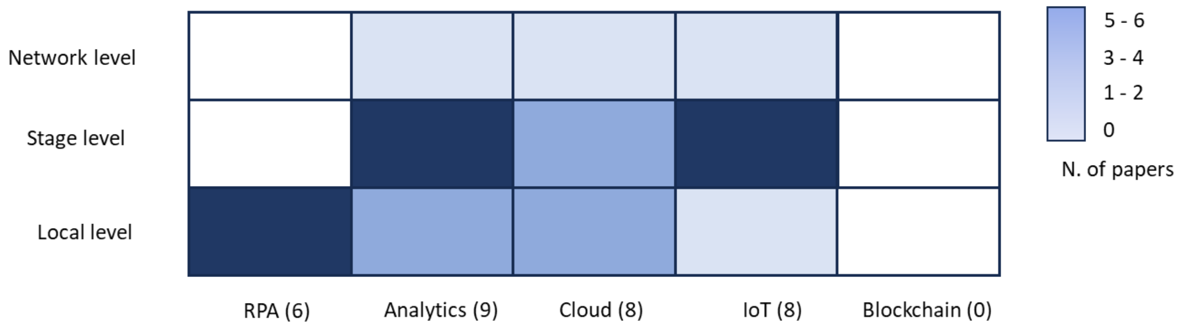

Figure 14: Presence of single technologies into integrated automation with different automation level of impact, on the base of number of papers describing them

9.4. Implementation roadmap

On the base of analysis performed in previous paragraphs, the following implementation roadmap is presented (Table 22).

Table 22: Implementation roadmap

<table>
<tr><td colspan="2">Have a clear and realistic automation strategy and share it across the organization.
Defining a clear direction of automation in relationship with SC goals is necessary before any practical implementation. Processes needs to be prioritization and the business model needs to be adapted. Business strategy and IT strategy should be aligned.
Management and workforce should be involved from the beginning in managing the change: assessing the as-is state of processes, maturity of IT infrastructures and technologies, and impact that SCA will bring in daily operations is fundamental.
Training and continuous learning culture should be developed.</td></tr>
<tr><td>IoT and Cloud introduction to automate data collection and monitoring.
Collecting, integrating, and monitoring data is the first step for being conscious of what is going on in the supply chain and therefore</td><td>RPA for tasks and transaction automation
Automation of recurrent transactions and standard tasks through RPA can represent a good first step toward automation, given the ease of RPA implementation, its relatively</td></tr>
</table>

acting to improve performance and reduce risks. More complex automation requires data quality and availability to be implemented effectively. Given the high costs of IoT sensors, its implementation should focus on most relevant SC processes and systems at first, and then gradually extend.	low cost, high availability on the market, and clear and measurable benefits achievable. In addition, higher data quality and process compliance are also good starting points for future more complex automation.
Advanced analytics for active monitoring and recommendation. Given the presence of an integrated, complete, and updated Cloud- database, a good automation evolution is implementation of AI and BDA-based algorithms for detection of changes and problems in the supply chain, and recommendation systems for supporting decision-making in selecting best reactions.	
Advanced analytics for prediction and planning automation Algorithms to automate forecasts and predictions represent a more complex step in the automation journey. To work effectively, they require data coming from great part of SC: this implies complexity in terms of big data management and analysis, as well as of development of the IoT infrastructure for data collection. A prior period for getting accustomed with such technologies can be of help for mastering the necessary skills and knowledge before automation of planning and forecasts.	
CPS Only when all above mentioned technologies are effectively implemented, mastered, and integrated among each other's, CPSs can take form, synchronizing and orchestrating all processes automation from data collection and monitoring, data analysis, decision making and automatic execution.	**SCDTs** Only when all above mentioned technologies are effectively implemented, mastered, and integrated among each other's, SCDTs modelling system can be implemented, to exploit the comprehensive dataset available and integrated in the Cloud environment, and AI capabilities to simulate and predict on the base of business needs, providing end-to-end visibility and optimum decision making.

Blockchain for automation of smart contracts

Blockchain should enter in the equation of SCA only when trust issues among partners are relevant, and ensuring authenticity of products and traceability and immutability of transactions is critical. Its application is indeed linked with great benefits in these directions, but at the same time deep challenges, especially for integration problems, high costs and complexity. Its integration with other technologies does not appear particularly relevant for expanding the scope of automation beyond transactions and data monitoring.

10 Conclusions

This chapter aims to discuss the main findings of this thesis, answering to research questions. Main limitations and future direction of the work will also be highlighted.

10.1. Discussion

After a systematic literature review, a more comprehensive definition of the concept of supply chain automation was elaborated: "The partial or full replacement 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. It involves integrating disruptive digital and operations technologies that reduce the dependencies of SC operations on human interventions."

10.1.1. RQ1 - Which are the key technologies available for supply chain automation?

The followings (Table 23) have been identified as key enabler of supply chain automation:

Table 23: Technologies definition

Technology	Definition
RPA	"A preconfigured and programmed software robot that automate repetitive manual tasks emulating human workers and their interactions with digital systems. It uses business rules and predefined activity choreography to automate the execution of a combination of business processes, activities, transactions, and tasks in one or more unrelated software systems to deliver a result or service with human exception management".
AI	"Technology that has a system's ability to correctly interpret data, understand relationships, learn from such data, and use those learning to achieve specific goals and tasks through flexible adaptation, providing visibility into operations, and support better decision making."
BDA	"Technology that treats ways to analyse and systematically extract information from large data sets".

Cloud	"A model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction"
IoT	"Physical devices that collect data, a network that transmits the collected data, and an application layer which includes IoT applications and services, to realize searching, identification, location, tracking, monitoring and management on the internet."
Blockchain	"Distributed, decentralized, digital ledgers sequentially linked using cryptography and supported by a network of multiple computers".
SCDTs	"A dynamic simulation model which features a long-term, bidirectional, and timely datalink to the real supply chain system. It aggregates the available data in a structured way and allows simulations on the supply chain's performance, identifying where volatility and uncertainty exist, as well as where optimization is possible. It also enables scenario planning so that a company can make decisions based on business needs."
CPS	"Systems of interconnected physical and computational objects, resulting in a close coupling of the cyber and physical contexts: assets and resources of the supply chain are integrated with computational components and can be monitored and controlled through computer-based algorithms"

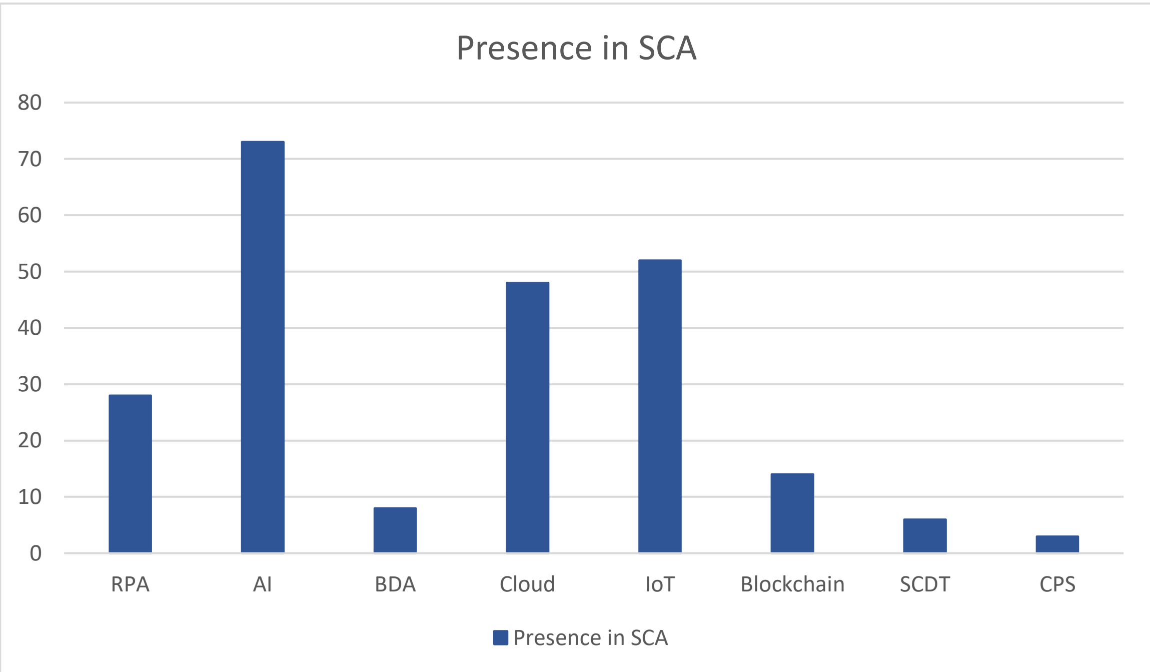

Figure 15: N. of mentions per technologies in SCA.

As visible by Figure 15, AI has been receiving higher attention from literature, given form one hand its superior cognitive capabilities, such as recognizing known and novel patterns and categories, logical reasoning and problem solving, and on the other hand the fact that it is not a mature technology yet. Cloud and IoT also appear as key technologies for SCA, usually found working together, and often embedded in complex automation, in support to other technologies effective functioning.

10.1.2. RQ2 - How can supply chain automation be operationalized?

To assess operationalization of SCA, technologies potential has been analysed to identify their roles for automation of different business processes, and also to see their readiness in reaching more complete and integrated level of SCA.

10.1.2.1. RQ2.2 - Which technologies are more suited for automation of which business processes?

SC business processes have been grouped under some macro-categories to better analyse them: data collection and monitoring, tasks execution, decision execution, predictions and recommendations systems, and planning automation.

A recap of the results obtained in terms of technology-business process automation fit is visually showed in Figure 9.

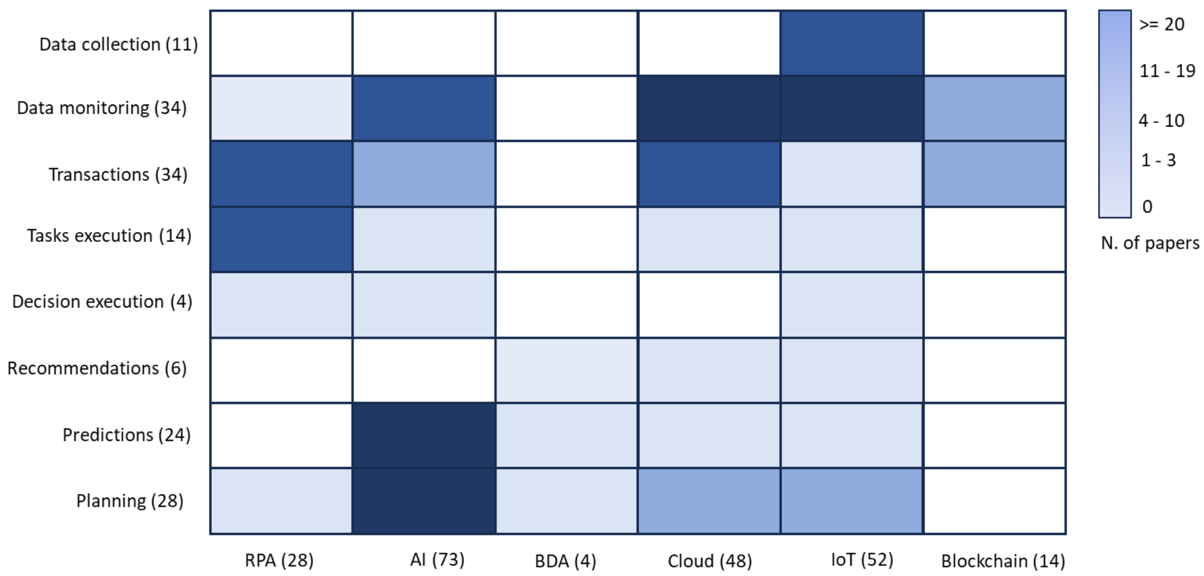

Figure 9: Heatmap of technologies enabling business process automation per number of papers.

Artificial intelligence finds perfect application for planning and predictions automation, reaching levels of accuracy and reactivity that go far beyond traditional methods. IoT and Cloud implementation appear particularly suited for automating data monitoring: IoT is critical for updated data collection and integration, and Cloud ensure sharing and orchestration of all relevant data on the internet so that partners have complete visibility, for data monitoring, track and trace and collaboration. Cloud is indeed also suitable for transactions of data among systems, especially through Cloud-based ERP systems.

Other combinations that appear as a good fit are:

- Automation of transactions and tasks execution through RPA.
- Data monitoring through AI, enabler of "active monitoring", for detection of changes and problems in the monitored data.
- Blockchain-based automation of transactions and their monitoring through smart contracts. This implementation is valuable when strict conditions related to data security and transactions and products traceability needs to be met.

10.1.2.2. RQ2.2. – What is the technological readiness of SCA in the direction of building an automated supply chain?

SCA can go beyond single and specific processes and embed the orchestration of several automated and integrated ones. This enlarges the automation scope and potential, as well as its impact on the supply chain. Final goal in this direction is the creation of an automated supply chain where the entire end-to-end flow, from procurement, production, transportation and logistics, inventory, delivery and demand management is automated, and data, decisions and execution are integrated and synchronized across all stages and actors.

Such automation initiatives were analysed to identify the current technological readiness, through two axes: automation completeness, assessing the level of required human intervention, and impact on SC, that can be local, on stage or on network level. Figure 10 graphically shows the distribution of integrated automation for impact and completeness.

At stage level, major attention is put toward procurement and production management automation. For the former, a completely automated solution was not identified, and [16] underliend how automatic execution of all the functions in the procurement process is still not achievable with single systems or applicatios. For the latter a more complete and comprehensive automation can be reached thanks to CPS application, that allows complete automation from data capture to monitoring, problems and changes detection, decision making and execution. This happens relying on IoT sensors, actuators, Cloud environment and AI-based algorithms.

The only automation reported that extends its impact across multiple stages and functions is based on SCDTs. It is able to capture data from all assets and nodes and aggregate them to model simulation of the whole network. This allows full system monitoring, control, visibility, and transparency, as well as problems detections and recommendation of optimal reaction. Trough simulations, it is possible to identify where volatility and uncertainty exist, as well as where optimization is possible This enables risk prediction, recommendations for risk mitigation, decision making and planning in an orchestrated way. Digital twins offer a completely new way for planning supply chains especially since it enables scenario planning on the base of the business needs. Even given the relevance of SCDTs for reaching automation on an orchestrated network level, it still requires human intervention for some decision making and implementation in the described application. In this context, integration of SCDTs into CPS could be an interesting solution, even if linked with high complexity and related huge investments.

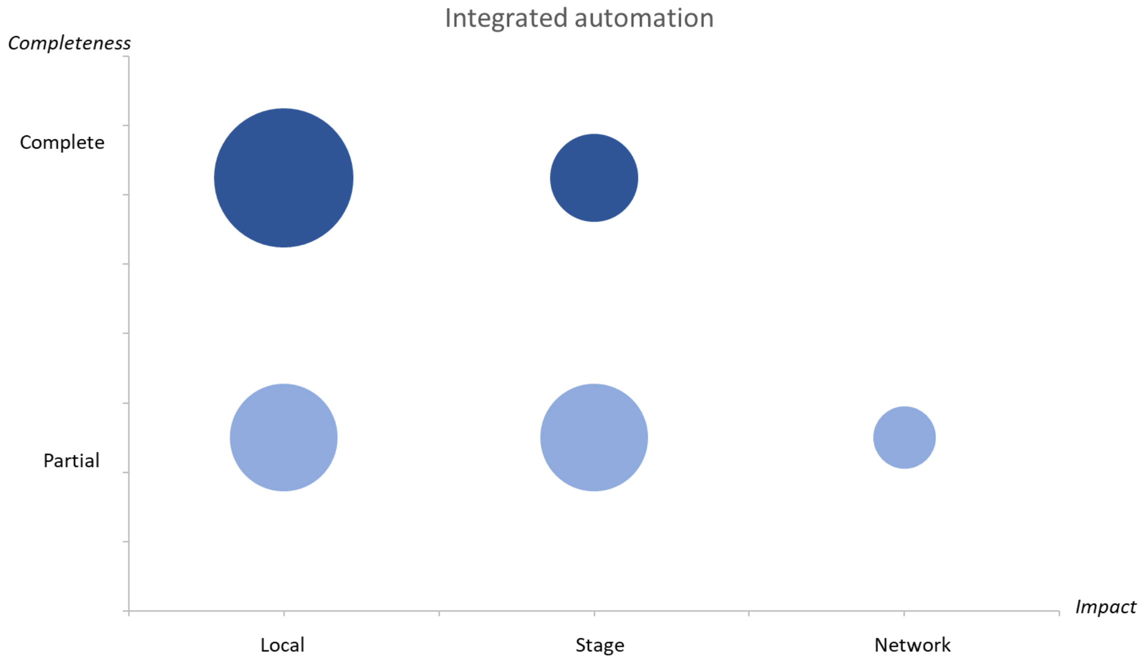

Figure 16: Integrated automation per impact and completeness level

What arises from the analysis is that the journey toward building an automated supply chain is still long, and that technology readiness is not sufficient yet.

Integration problems among technologies and systems appear to be the most relevant barrier in building a more complete SCA, as well as organizational readiness: companies require a clear strategy, business model, roadmap for and management support to drive the change.

10.1.3. RQ3 – Which are managerial implications of supply chain automation?

Several dimensions have been analysed to assess the best way for companies to approach automation, and therefore define an implementation roadmap.

Firstly, key challenges in implementation of each technology, to identify which ones are easier to be implemented sooner or later in the automation journey. Advanced analytics seems to be the most complex technology to implement, considering challenges such as difficulty to reach the needed skills, data requirements, integration challenges and privacy and security concerns. Adoption of IoT and Cloud for data capture and monitoring seems a needed pre-requisite, to provide a reliable, shared, complete, and updated dataset. Same can be concluded for RPA-based transactions automation, that improve quality and completeness of data and reliability of processes. Lack of a clear vision, resistance to change and integration between technologies and systems, represent the most discussed challenges in general.

Secondly, relevance of benefits arising from adoption of different technologies, to identify which may lead to greatest positive impact on supply chain performances. Analytics- and cloud-based automation are the ones showing greater global benefits, which impact is extended on the whole SC performances, with particular focus on supply chain visibility, profitability, and stakeholders' collaboration.

Finally, presence of single technologies in integrated automation described in paragraph 8.1 is analysed, to understand which are more relevant in the direction of building an automated supply chain. Results of the analysis shows relevance of Analytics, Cloud and IoT integration. They are also the key components of both CPS and SCDTs, technologies having the greater automation capabilities at stage and network level. The implementation roadmap identified is showed in Table 22.

10.2. Work limitations

This work is purely based on a systematic literature review. The lack of practical case studies as well as the limited number of papers taken into consideration surely represents the main limitations of results accuracy and relevance.

10.3. Future directions

Future directions of this research could be focused on:

- Perform practical case studies to better understand the effects related to automation, on the base of different technologies. Analysing their impact and relevance given different industries, companies dimensions or SC goals may be interesting.
- Deeper analyse integration problems registered by companies when combining different technology and IT systems. Identification of best practices to overcome this barrier is also relevant.
- Deeper study the implementation roadmap, starting from interviews to companies and practical case studies, to identify major challenges encountered in each step and how these where overcame, as well as managerial practices to ensure smooth success of each technology implementation.

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12 List of tables

13 List of figures