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LITERATURE REVIEW

Supply chain management and industry 4.0: a theoretical approach

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ABSTRACT

Goal: The purpose of this study is to analyze how the elements of industry 4.0 relate to Supply Chain Management (SCM) by identifying mechanisms that promote or include these elements in the supply chain. The elements of industry 4.0 relate to the basic processes of Supply Chain Operations Reference (SCOR) when considering the literature on the subject.

Design / Methodology / Approach: A systematic literature review was performed, and 293 articles were selected and analyzed. Content analyses were conducted to identify the main contributions of elements in SCM, explaining the mechanisms that promote or include elements in SCM and relating the elements to the basic processes of the SCOR model.

Results: From the literature analysis, theoretical relations between the elements of industry 4.0 and SCM were established. An overview on the subject was provided, filling a gap in the literature. Identifying the mechanisms that promote or include elements in supply chains and the relations of elements to the SCOR model may help to guide managers for future applications of this model in a targeted manner.

Limitations of the investigation: This study covers only theoretical analysis on the concepts, that is, no real applications were made considering the topics addressed.

Originality/Value: The construction of a theoretical framework based on systematic literature review on SCM and Industry 4.0 is a contribution to the bibliographic database. Another contribution is the identification and analysis of the main contributions of elements to SCM in the processes of the SCOR model.

Keywords: Supply chain management; Industry 4.0; Big data; Internet of things; Simulation.

INTRODUCTION

The fourth industrial revolution has been promoting the use of innovative technologies such as advanced robotics, artificial intelligence, data processing and data exchange techniques, internet of things and other technologies (Forum, 2017). This movement generates changes that directly impact supply chain management (Szozda, 2017). It turns operational activities previously isolated into automated activities fully integrated with the value chain (Strange and Zucchella, 2017). In this sense, it is necessary that industries seek innovations in supply chain management (SCM) to stay updated and competitive in the market in which they act (Rodriguez and Cunha, 2018). To do so, companies must incorporate existing technologies into their processes to achieve competitiveness and sustainability along the supply chain (Majeed and Rupasinghe, 2017).

Innovation in SCM is a key factor for industries to access new opportunities and maintain their competitive advantage in today's business dynamics. Therefore, innovation must be well managed and implemented (Li and Li, 2017). However, industries have been facing problems in integrating

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technologies into their supply chains. This leads to financial difficulties and inadequate chain management practices (Majeed and Rupasinghe, 2017).

Among the technologies transforming traditional industries into intelligent industries, or industries 4.0, there are nine technological elements: autonomous robots, simulation, horizontal and vertical integration systems, internet of things, data security, cloud computing, additive manufacturing, augmented reality, big data and data analysis (Boston Group, 2015). Studies conducted by Ghobakhloo (2018), Ardito et al. (2018) and Chukwuekwe et al. (2016) considered some of these elements as essential for the implementation of industry 4.0 within organizations.

In this sense, incorporating industry 4.0 technologies into SCM helps to build a more responsive supply chain. It provides continuous process monitoring and fast adaptation to business complexity (Kersten et al., 2017). In addition, studying technologies such as big data and data analysis may contribute to achieving SCM agility (Waller and Fawcett, 2013). Because of this, understanding how industry 4.0 technologies are related to SCM is an important factor for the development of this topic (Orenstein et al., 2016).

In order to identify how industry 4.0 technologies are present in SCM, as well as the diverse applications they enable, this study aims to conduct a systematic literature review on the relationship of industry 4.0 technologies with SCM. The identification and analysis of these technologies in SCM aims to provide an overview on the subject and contribute to the understanding of the diverse applications of these technologies. The literature overview allows taking a better advantage of technologies within current and future scenarios (Ardito et al., 2018).

This study seeks to contribute to identify and describe, from a systematic literature review, which mechanisms are used to include or promote the use of industry 4.0 elements in SCM. In addition, this study intends to categorize the elements of industry 4.0 according to the main processes of the model supply chain operations reference (SCOR) by analyzing relations established by analyzing the literature. Such categorization aims to verify how each element of industry 4.0 relates to the basic processes of the SCOR model, and how this relationship can contribute to the performance of supply chains.

This study is divided into six sections besides this introduction. In the following section, the concepts associated with SCM and industry 4.0 and the SCOR model are described. The third section presents the methodological procedures used in this study, as well as inclusion criteria used to analyze publications. The fourth section presents a descriptive

analysis of studies selected by the systematic literature review. Then, the results obtained during the research are presented and discussed. Finally, the conclusions of the study, its limitations and perspectives of future research are explained.

THEORETICAL FRAMEWORK

This section presents theoretical references to explain the main concepts that supported the development of this study. The concepts related to supply chain management, industry 4.0 and the SCOR (Supply Chain Operations Reference) are discussed.

Supply chain management and industry 4.0

SCM is a way of linking suppliers, factories, warehouses and stores so that products arrive at the right quantity, at the right place and at the right time, ensuring strategic supply chain integration (Orenstein et al., 2016). To ensure such strategic integration, SCM needs to relate information flows and materials to different links inside the supply chain (Sikilero et al., 2015).

Through information flow and materials, it is possible to transform and provide the necessary services from the supply of raw material to the distribution to final customers, thus ensuring the success of the business (Ballou, 2006). For this to happen, it is important that information flows be well structured (Mendel et al., 2011). In this context, one of the objectives of industry 4.0 is to ensure that information be available in real time, integrate and connect the different links in the supply chain (Orenstein et al., 2016). In this way, industry 4.0 contributes to the structuring of information flow in the supply chain.

Industry 4.0 technologies contribute to SCM as they integrate data from a network of organizations with cloud storage, facilitating mass data analysis (Szozda, 2017). In addition, technologies such as Internet of Things (IoT) enable promoting new opportunities for improvement, thus ensuring a competitive advantage (Li and Li, 2017).

The advance of industry 4.0 provides for the creation of new supply chains because the connectivity generated by this revolution opens up new forms of integration between organizations (Forum, 2017). However, the relationship between industry 4.0 and SCM is a not yet explored market. The use of available technologies is still not common in organizations (Szozda, 2017).

Supply Chain Operations Reference (SCOR)

Supply chain operations reference is a model developed by the Supply Chain Council that aims to link business processes, metrics and best practices into a single structure in order to sustain communication between different members of the supply chain (Supply Chain Council, 2013). This structure improves the efficiency of the supply chain and promotes improvement activities in chain management (Ahumada, 2016). In addition, SCOR defines

process management descriptions at all company levels, such as activities, operations and tasks (Moreno et al., 2016).

The SCOR model is divided into two parts. The first part is responsible for modeling supply chain processes through diagrams and frameworks; the second part is responsible for creating indicators that evaluate the performance of these processes (Lepori and Bollecker, 2018). According to the Supply Chain Council (2013), the model is organized into six basic processes: plan, source, make, deliver, return and enable. Table 1 shows the concepts of these basic processes as defined by the Supply Chain Council (2013).

Table 1 - Definitions of the basic processes of the SCOR model.

Process	Definition
Planning	Processes associated with determining requirements and correctiveactions to achieve the objectives of the supply chain.
Source	Processes associated with ordering, delivering, receiving and transferring raw materials, sub-assemblies, products and/or services.
Production	Processes of adding value to the products through mixing, separation, conformation, machining and chemical processes.
Deliver	Processes associated with executing order management and order servicing activities.
Devolutions	Processes associated with transferring material from a customer backinto the supply chain to solve defects in the product, order or manufacturing, or to perform maintenance activities.
Enable	Processes associated with the establishment, maintenance and monitoring of information, relationships, resources, assets, business rules, compliance and contracts necessary to operate the supply chain.

Source: Supply Chain Council (2013).

According to the Supply Chain Council (2013), in order to evaluate the performance of the supply chain, the SCOR model defines five evaluation criteria, each of which has its performance indicators. Table 2 lists the evaluation criteria of performance indicators.

Table 2 - Definition of evaluation criteria of the SCOR model.

Evaluation criteria	Definition
Reliability	Ability to perform tasks as expected. Typical metrics for reliability:timely orders, right quantity and right quality.
Responsiveness	Speed with which tasks are performed. Examples include cycle timemetrics.
Agility	Ability to respond to external influences, ability to respond to changesin the market to obtain or maintain a competitive advantage. SCOR agility metrics include flexibility and adaptability.
Costs	Cost of operating supply chain processes. A typical cost metric is costof goods sold.

Assets	Ability to use assets efficiently. Metrics include days of supply stockand use of capacity.

Source: Supply Chain Council (2013).

The use of evaluation criteria of the SCOR model allows organizations to have a modern management oriented to ensure customer satisfaction, increase flexibility of delivery, product reliability, and reduce costs (Minculete and Olar, 2018). There are several approaches to measuring the performance of supply chains. However, the SCOR model is the most comprehensive and has been used by several companies wishing to improve their performance (Kocao and Mehmet, 2013). Identifying performance indicators facilitates the control of supply chain processes and allows including or changing operational activities to guarantee the performance of each evaluation criterion (Vidal et al., 2016).

METHODOLOGICAL PROCEDURES

To develop this study, a systematic literature review was conducted to identify how the main elements of industry 4.0 relate to SCM. Thus, the method proposed by Morandi and Camargo (2015), according to Figure 1, was followed and adapted.

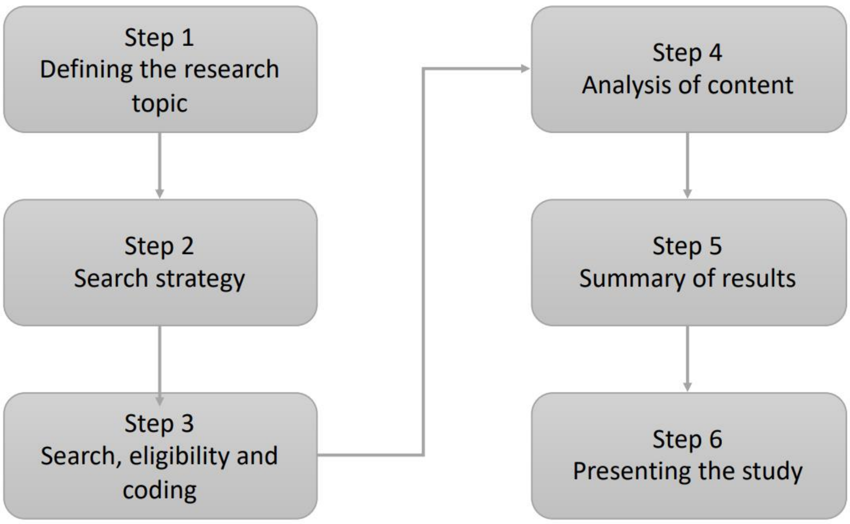

Figure 1: Work method.
Source: Adapted from Morandi and Camargo (2015).

To begin this study, the topic to be addressed by the systematic literature review was defined in step 1. The central theme of this study is to understand how the main elements of industry 4.0 relate to SCM. In order to understand this issue, a configurative review was carried out. This review method is proper to answer questions of open-ended research, which seeks to explore the subject more broadly (Morandi and Camargo, 2015).

The search strategy was defined in step 2. The first stage was to determine search terms. The terms were defined by exploratory searches. Root terms were chosen based on the previous knowledge of the researchers because this a topic has been present in the literature for a long time. However, linking terms were defined based on the elements of industry 4.0 identified by the Boston Group (2015) analysis. This analysis brings together elements identified in several studies, like: Ghobakhloo (2018), Ardito et al. (2018), Chukwuekwe et al. (2016) and Kang et al. (2016). Thus, academic research and the business view demonstrated by the Boston Group (2015) analysis were compiled. The search terms were defined in English and are shown in Table 3.

Table 3 - Terms used.

Search term	
Root term	**Linking term**
supply chain management, supply chain e logistics	autonomous robots, simulation, internet of things, IOT, horizontal system integration, vertical system integration, horizontal and vertical system integration, cybersecurity, cloud, additive manufacturing, augmented reality, big data and big data and analytics

The second stage was to define the source of the search. It is an indispensable step in the formulation of a good strategy (Morandi and Camargo, 2015). For this study, the search index by abstracts present in the EBSCOHost database was used, which includes 21 databases that, together, contain approximately 29,000 indexed scientific journals.

The third step is to define inclusion and exclusion criteria. Duplicate articles, articles not adherent and relevant to the research, and articles not in English, Portuguese or Spanish were excluded from this research. Both the root terms and linking terms were joined by the Boolean operator "OR" and connected with the Boolean operator "AND". The result of the search is consolidated in Table 4.

Table 4 - Quantitative search results.

Source	Search term	Index	No. of studies
EbscoHost	(AB ("supply chain management" OR "Supply chain" OR "Logistics")) AND (AB ("autonomousrobots" OR "simulation" OR "horizontal system integration" OR "vertical system integration" OR "horizontal and vertical system integration" OR "internet of things" OR "IOT" OR "cybersecurity"OR "cloud" OR "Additive manufacturing" OR "augmented reality" OR "Big data" OR "Big Data and Analytics"))	Abstract	3,381

Step 3 refers to searching, eligibility and coding. According to Morandi and Camargo (2015), after the definition of the search for primary studies, a selection to evaluate the results is important. In the selection of studies, the titles of all files were read. Duplicates and articles not in English, Portuguese and Spanish were removed. The studies selected after reading the titles went through another filtering stage. The abstracts were read and only the studies adherent and relevant to the research were selected. The consolidation of this stage is shown in Table 5.

Table 5 - Consolidation of results.

Search filter	No. of studies
Total - EbscoHost	3,381
Elimination of duplicates and articles not in the English, Portuguese or Spanish	2,551
Reading of titles	2,551
Reading of abstracts	548
Selected texts	293

By content analysis, it is possible to interpret characteristics and patterns among the observed documents, so that a set of evidences can be categorized and examined (Bardin, 2011). Considering this technique, the following analyses of the selected texts were performed in step 4: (i) identification of main contributions of elements in the industry 4.0 to the SCM; (ii) identification of mechanisms promoting the inclusion and the promotion of elements of industry 4.0 in SCM; and (iii) relationship of elements of industry 4.0 with basic processes of the SCOR model. For the operation of this step, the software Atlas.ti 8® was used.

According to Morandi and Camargo (2015), the synthesis of results (step 5) creates a relationship between the selected texts, providing a theoretical contribution on the subject. To accomplish this, the content analysis and the descriptive analysis of the selected texts were conducted. The objective is to establish a macro view of the subject. These analyses served as a basis for the development of this study. The last step concerns the presentation of the study, demonstrating how elements of industry 4.0 relate to SCM. The last step also presents the mechanisms that promote the inclusion and elements in the SCM, as well as relations established with the SCOR model. The presentation of the study aims to contribute to the understanding of the subject and to the development of future research related to the topic.

DESCRIPTIVE ANALYSIS

There were 293 studies for analysis after the selection of articles. Before performing content analysis, a descriptive analysis was performed using the correlation of keywords of the selected studies. To do this, all files have been added into the Mendeley® scientific research organization software. After that, information was extracted and used to feed the VOSviewer® bibliometric analysis software. The result of the correlation of keywords is shown in Figure 2.

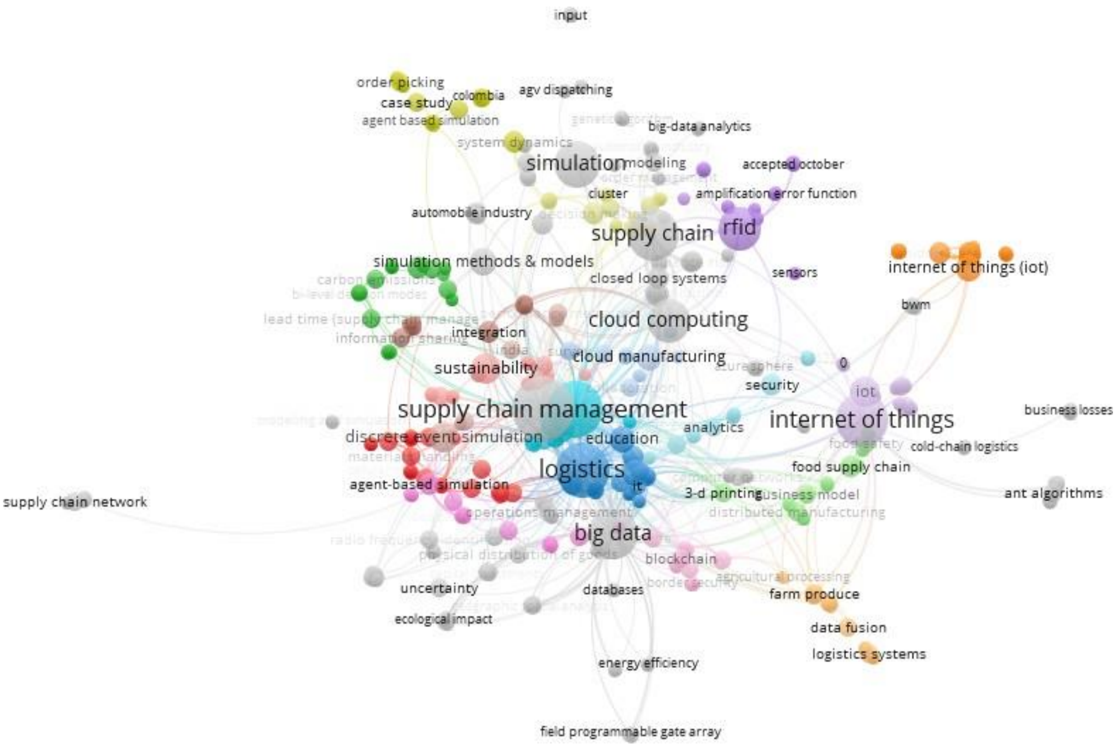

Figure 2 - Correlation of keywords.

For the construction of correlations, the criterion of occurrence "at least once" was used in order to verify the relation of the root term with linking terms comprehensively. The words in the red zone were the most correlated among the articles selected. Thus, from the observed correlations, one of the root terms, "supply chain management", is strongly related to some linking terms, showing that the terms selected are in agreement with the existing literature.

This a posteriori verification of the initial reading helps to understand what is being disclosed by the literature and what needs to be read more carefully. From correlations, it is possible to perceive which linking term is most strongly connected or not with the root term.

Regarding the temporal distribution of studies, the studies were published between 2005 and 2022. Studies published between 2016 and 2022 represented about 80% of the articles selected for analysis. Figure 3 shows the distribution of articles over time.

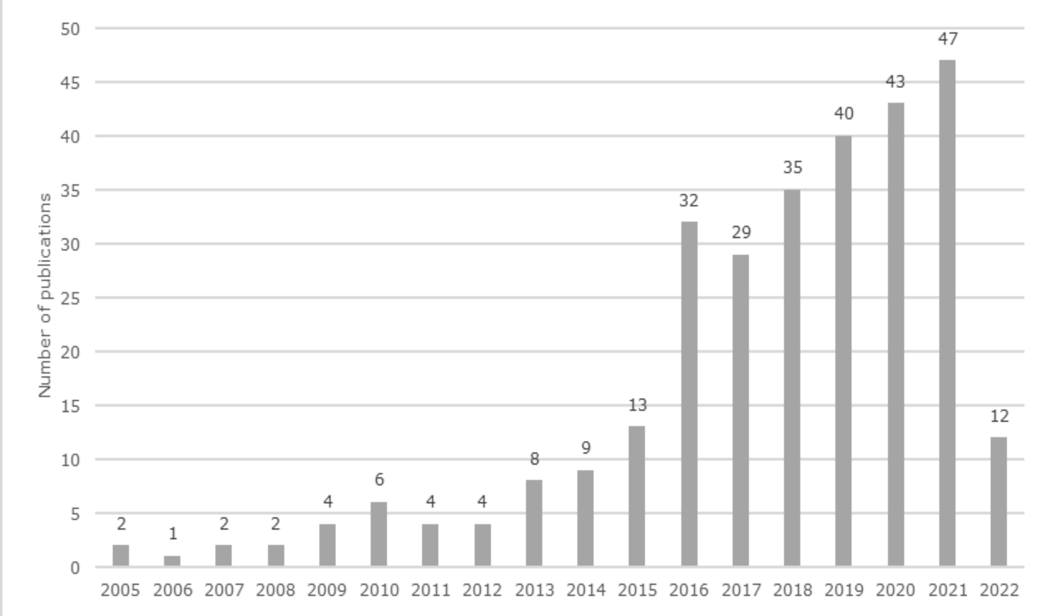

Figure 3 - Temporal distribution of articles.

The growth seen as of 2011 can be explained by the German government's encouragement to introduce industry 4.0 concepts to build new business models based on smart grids, as pointed out by (Kang et al., 2016). The low number of studies in 2022 compared to 2021 is explained by the search in the database, which happened in June 2022.

In relation to the main journals where studies have been published, Table 6 presents the journals identified with five or more publications. Associated with the number of journals in each journal, the JCR impact factor (Journal Citation Reports) was included to demonstrate the relevance of the journal. The journals are justified by topic scope and characteristics of each topic.

Table 6 - Journals identified with five or more publications.

Journal	Number of publications	JCR Impact Factor (2021)
International Journal of Advanced Manufacturing Technology	15	3.563
Journal of Cleaner Production	13	11.072
International Journal of Production Research	10	8.568
Journal of Business Logistics	8	6.677

The International Journal of Advanced Manufacturing Technology is included due to the integration of processes and the use of technologies such as simulations, additive manufacturing and intelligent manufacturing. The Journal of Cleaner Production, meanwhile, can be included due to the introduction of technologies that contribute to the sustainability of the supply chain. The International Journal of Production Research is included due to operations management research. Finally, the Journal of Business Logistics is included due to the nature of publications focused on the central theme of this study. The other journals were not included because the number of publications on the subject was limited.

RESULTS AND DISCUSSION

In this section, the main results of the research are presented. This section is divided in three parts. The first part shows the main contributions identified by the systematic literature review, explaining the relations among the elements in industry 4.0 and SCM. The second part explains the mechanisms for inclusion and promotion of elements of industry 4.0 in SCM. The last section presents the established relations of industry 4.0 elements with the SCOR model.

Main contributions

From content analysis, it was possible to verify how the elements of industry 4.0 related to SCM. In this section, we present the main contributions and relations with the proposed theme by the following elements present in industry 4.0: autonomous robots, simulation, internet of things, cloud computing, additive manufacturing, augmented reality and big data.

Autonomous Robots and Supply Chain Management

Autonomous robots or self-guided vehicles are key equipment for the development of factories that want to become intelligent (Yin and Zhao, 2013). Such devices are incorporated at organizations' operational level. Thus, they influence the complexity of the operations since there are new variables to be controlled (Cardarelli et al., 2017). They are usually incorporated into transport of materials between different points, both internally and externally (Gružauskas et al., 2018).

Autonomous robots promote a radical innovation in several processes, such as inventory handling and support to internal and external logistics services (Bechtsis et al., 2018). In addition, such devices provide benefits in several respects, such as transport safety, as they are controlled by different sensors and regulated by technical standards. Thus, they contribute to reduce the risk of material damage and, thus, to reduce costs (Gružauskas et al., 2018).

Such equipment requires a high initial capital investment. However, they enable the development of a SCM with minimal human interference (Gružauskas et al., 2018). In order to achieve such a dynamic management, other elements of the industry 4.0 need to be incorporated into the development of such technologies, such as internet of things, simulation (Bechtsis et al., 2018) and big data (Gružauskas et al., 2018).

One of the most significant advantages of using autonomous robots in SCM is that they can greatly increase the efficiency of the supply chain (Fernández-Caramés et al., 2019). This is because autonomous robots can work around the clock without needing breaks and can also be quickly deployed to new locations if needed (Shamout et al., 2022). This means that more goods can be produced in a shorter time frame, which can lead to significant cost savings.

Another advantage of using autonomous robots is that they can offer a higher degree of accuracy than traditional methods. This is because robots can be programmed to follow very specific instructions and to carry out tasks with a high degree of precision. This is particularly beneficial in industries where accuracy is critical, such as the medical and pharmaceutical industries (Casamayor-Pujol et al., 2020).

Simulation and supply chain management

Simulation is used for the development, projection and analysis of SCM. It is a tool for decision-making (Straka et al., 2018). Regarding decision-making, several applications are included in the SCM context, such as simulation of picking (Chackelson et al., 2013), simulation of cross-docking (Buijs et al., 2016), simulation for inventory optimization (Suraj et al., 2016), optimization model (Zhao et al., 2017), among others.

While simulation can be used to study any aspect of the supply chain, it is particularly well-suited to studying transportation and logistics systems. These systems are often complex, with many different elements that need to be coordinated in order for the system to function smoothly (Ali et al., 2020). By simulating the system, managers can test different configurations and identify the most efficient way to operate the system (Wiśniewski and Szymański, 2021).

In this sense, simulations can be used in activities that require re-planning of layouts and validation of production flows, contributing to logistic planning (Da Silva and Kaminski, 2015). In addition, through computational simulation, it is possible to evaluate strategies for the allocation of orders from different clusters and to combine different market scenarios, demonstrating all impacts to members of the supply chain (Renna and Perrone, 2015). Simulation can also be used to study the impact of disruptions on the supply chain. By simulating different types of disruptions, managers can identify the most vulnerable parts of the system and develop contingency plans to minimize the impact of disruptions (Ju et al., 2022).

Computational simulation, when aligned with technologies such as Radio Frequency Identification (RFID), can be used to develop more robust internal logistics processes (Ross et al., 2009). RFID enables collecting various information, such as storage identification and expiration date. This information serves to build a more robust database and thus contribute to a more accurate simulation model since data are collected and available (Bottani, 2008).

Internet of Things and supply chain management

Internet of Things, or IoT, is a mechanism that connects the physical world to the digital world through the internet taking advantage of a network of sensors to leverage wireless communications (Cheng et al., 2014). Some benefits of Internet of Things is to improve the performance of the companies, specially the improvements related to "speed" and "dependability" (Brunheroto et al., 2021). The benefits provided by IoT to SCM are related

to the use of technology to connect machines, products and people in real time and generate data that can be used throughout the supply chain (Szozda, 2017).

Several technologies are being developed using the concept of IoT, such as sensors, drones, autonomous robots, among others (Brewster et al., 2017). Such technologies allow guaranteeing for the SCM the quality of shipment, location of items, tracking of fleets and control of information flows between the different links of the supply chain (Aksentijević et al., 2015). In addition, IoT allows companies to respond rapidly as operations are alerted instantly through effective collaborations (Ben-daya et al., 2017).

Despite the potential benefits, there are also a few challenges that need to be addressed in order to fully realize the potential of IoT in SCM. These challenges include data security and privacy, scalability, and standards (Koot et al., 2021).

Data security and privacy are a major concern when it comes to IoT. This is because IoT devices collect and exchange a large amount of data, which could be accessed and used without the consent of the individuals involved (Koot et al., 2021; Sun et al., 2022). In order to address this concern, it is important to ensure that IoT devices are properly secured, and that data is collected and used in accordance with data privacy laws (Misra et al., 2022).

Scalability is another challenge that needs to be addressed in order to fully realize the potential of IoT in SCM (Koot et al., 2021; Sun et al., 2022). This is because the number of IoT devices is expected to grow exponentially in the coming years. In order to accommodate this growth, it is necessary to have a scalable infrastructure in place.

Standards are also a challenge that needs to be addressed in order to fully realize the potential of IoT in SCM (Koot et al., 2021; Sun et al., 2022). This is because there is currently no standardization for IoT devices. This lack of standardization makes it difficult for different devices to communicate with each other, which limits the potential of IoT(Ahmed et al., 2021).

Despite the challenges, IoT has the potential to transform SCM. By providing real-time visibility into the location and condition of inventory, as well as the ability to track and manage the flow of goods throughout the supply chain, IoT has the potential to improve efficiency, accuracy, and customer satisfaction while reducing costs (Gray-Hawkins et al., 2019).

With the growth of IoT and the benefits it can bring, SCM needs to adapt to emerging business models in order to create new competitive advantages ((Li and Li, 2017)). In order to adapt to this context, it is necessary to relate IoT to other elements of the industry 4.0, such as cloud computing (Chen et al., 2014), big data (Giagnocavo et al., 2017) and autonomous robots (Gromovs and Lammi, 2017).

Cloud computing and supply chain management

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 (Li et al., 2019). Furthermore, cloud computing operates on networks using virtual features. Its main characteristic is to be unlimited in data storage size (Gowda and Subramanya, 2017). SCM is leveraging this technology for decision-making, capacity-building and collaboration with the various supply chain links (Gowda and Subramanya, 2016).

Cloud computing is a support for the creation of supply chain service management platforms considering that it fosters integration between different points in the supply chain such as warehouses, suppliers, conveyors, and customers (Yan et al., 2014). Another advantage of using cloud computing is the ability to visualize real-time data generation, providing information to improve the management of industry operations and thereby improving SCM (Chen et al., 2014).

The use of cloud computing in SCM may contribute to the creation of a competitive advantage because its use allows a broader and more comprehensive view of the network ((Subramanian et al., 2015). For this, it is necessary that other elements of the industry

4.0 be related to cloud computing and SCM, such as autonomous robots (Cardarelli et al., 2017), internet of things and big data (Yan et al., 2014).

In this sense, the benefits of using cloud computing in SCM are many and varied. Perhaps the most significant is the ability to improve communication and collaboration between supply chain partners. By using cloud-based applications, organizations can share information in real-time, which can help to improve decision-making, reduce costs and improve customer service (Li et al., 2019). In addition, the use of cloud computing can help to reduce the need for physical infrastructure and increase flexibility, as organizations can scale up or down their use of resources as required (Fu et al., 2021).

Despite the many benefits of using cloud computing in SCM, there are also some challenges that need to be considered. One of the main challenges is security, as sensitive data is stored remotely, and organizations need to be sure that their data is safe and secure (Yang et al., 2017). In addition, there is a risk that organizations will become reliant on their cloud service provider, and if the service is interrupted, this could have a significant impact on operations (Fu et al., 2021).

Additive manufacturing and supply chain management

Additive manufacturing, or 3D printing, presents new challenges for SCM. In traditional SCM, manufacturing is based on subtractive processes, in which parts are created by removing material from a raw piece of stock. In contrast, additive manufacturing builds parts by successively adding material, typically in the form of layer-upon-layer of powder or liquid (Wu et al., 2022). Thus, additive manufacturing is responsible for the fabrication of parts based on a solid computerized 3D model to which layer-by-layer material is added (Huang et al., 2013). For SCM, additive manufacturing contributes to supply chain efficiency because it reduces costs with distribution channels since the printer may be directly connected to point of use (Attaran, 2017). Moreover, according to (Thomas, 2016), other positive effects of additive manufacturing in the supply chain is inventory assertiveness and low risk of supply disruption, since manufacturing takes place at the point of use.

According to (Attaran, 2017), the impacts generated by additive manufacturing on supply chain management are diverse, such as point of use manufacturing, reduction of delivery lead time, reduction of ready product stock, reduction of economic batch, among others. In addition, according to (Huang et al., 2013), additive manufacturing provides an agile and low-cost supply chain as it brings various links in the supply chain closer together. In the studies selected for analysis, no relationship of additive manufacturing was found with the other elements of industry 4.0.

There are four key areas in which additive manufacturing is having an impact on SCM: (1) the need for new types of materials; (2) the need for new types of equipment; (3) the need for new approaches to inventory management; and (4) the need for new approaches to quality control (Sonar et al., 2022).

Augmented reality and supply chain management

Augmented reality is a technology that superimposes computer-generated images on a user's view of the real world, providing a composite view of both virtual and real worlds and it has the potential to revolutionize SCM by providing real-time information on inventory levels, whereabouts of assets, and status of shipments (Akbari et al., 2022). According to (Reif et al., 2010), augmented reality is a technology that aims to support human beings in visual perception.

In SCM, augmented reality may contribute to the separation of orders (picking) in internal logistics. It can improve information visualization and, consequently, the assertiveness of operation (Reif et al., 2010). The use of augmented reality in SCM is expected to provide numerous benefits such as increased accuracy and efficiency in inventory management, improved customer satisfaction through real-time tracking of shipments, and reduced costs associated with errors in fulfillment (Akbari et al., 2022). In addition, augmented reality can provide a competitive advantage to companies that adopt it early (Bhattacharya and Chatterjee, 2022).

Despite the numerous potential benefits, there are also some challenges associated with the use of augmented reality in SCM (Akbari et al., 2022). One of the biggest challenges is the lack of standardization in augmented reality technology, which makes it difficult to develop applications that can be used across different platforms (Bhattacharya and Chatterjee, 2022). In addition, the cost of augmented reality headsets and other hardware can be prohibitive for some companies (Akbari et al., 2022).

Future research should address augmented reality in the following applications: vehicle loading, control of international materials, and instructions for material standardization. This verification aims to understand how technology will behave in face of new applications.

Big data analysis and supply chain management

According to (Sanders, 2016), the ability to gather, store, aggregate and analyze data generated by information systems is the precise definition of big data analysis. In SCM, big data analysis may contribute to the pricing strategy and the purchase of raw material, since supply chain members are known (Liu, 2017). On the other hand, big data analysis requires a strong interaction with experts. Often, the information received has not yet been transformed into structured data, and this requires intelligent processing and analysis (Wolfert et al., 2017).

It is possible to explore several analytical resources using big data, such as understanding the demand and mitigating uncertainties, thus contributing to the formulation of assertive strategies (Biswas and Sen, 2016). Also, implementing enabling technologies in supply chain can provide better visibility into future customer demand, contributing to better forecasts (Barbalho and Dantas, 2021). In addition, the use of big data promotes supply chain innovation and sustainability as it promotes different data analyses within management and interconnection with different members of the value chain (Rodriguez and Cunha, 2018).

Another way in which big data can be used in SCM is to optimize routing and shipping. Big data can be used to track the movement of goods and identify bottlenecks and inefficiencies. This information can then be used to plan more efficient shipping routes and schedules. Big data can also be used to improve inventory management, where the technology can be used to track inventory levels and identify patterns in customer demand (Koot et al., 2021). This information can help businesses to avoid over-stocking or under- stocking their products.

There are many other ways in which big data can be used to improve SCM. The above examples are just a few of the ways in which big data can be used. As the volume of data continues to grow, so too will the opportunities to use big data to improve supply chain management (Koot et al., 2021).

In addition, big data analysis provides advantages for decision-making as it is possible to forecast demand, target marketing campaigns, and assess supplier risks by analyzing data (Sanders, 2016). The industry 4.0 elements related to big data and SCM are internet of things and cloud computing (Zhong et al., 2016).

Summary of contributions

One of the contributions of this study is to understand how elements of the industry 4.0 relate to SCM. This issue has been emerging in the current context in academia and organizations. The elements were analyzed in order to understand their main contributions to SCM and to leverage knowledge about the proposed theme since there is a future tendency towards the construction of intelligent distribution networks (Szozda, 2017).

Through a systematic literature review, it was possible to verify a correlation between linking terms and a root term. This correlation was determined using association rules. An association rule is a statement that describes how frequently itemsets occur together in a dataset. In this research, the dataset was created through content analysis. During content analysis, each article received one or more labels, where labels are the elements of industry 4.0. For example, if Article A present the Internet of Things and Big Data, he will receive two labels: Internet of Things and Big Data. As result, these association rules were created, and each combination was analyzed. Table 7 shows association rules and reference's example. In this sense, correlation is the relationships between pieces of content, such as which topics are frequently mentioned together. Figure 4 exemplifies the correlations of the root term to linking terms based on association rules.

Table 7 - Association rules.

Association rules	References' examples that sustain the secondary correlation
Autonomous Robots, Simulation	(Bechtsis et al., 2018; Casamayor-Pujol et al., 2020; Green, 2020)
Internet of Things, Cloud Computing, Big Data	(Chen et al., 2014; Fu et al., 2021; Misraet al., 2022; Szozda, 2017)

Internet of Things, Big Data	(Chen et al., 2014; Fu et al., 2021; Misraet al., 2022; Szozda, 2017)
Internet of Thing, Cloud Computing	(Fernández-Caramés et al., 2019; Gawankar et al., 2020; Kovacova et al., 2020)
Cloud Computing, Big Data	(Firescu et al., 2013)
Cloud Computing, Autonomous Robots	(Fernández-Caramés et al., 2019)
Simulation, Big Data	(Wiśniewski and Szymański, 2021; Zhaoet al., 2017)

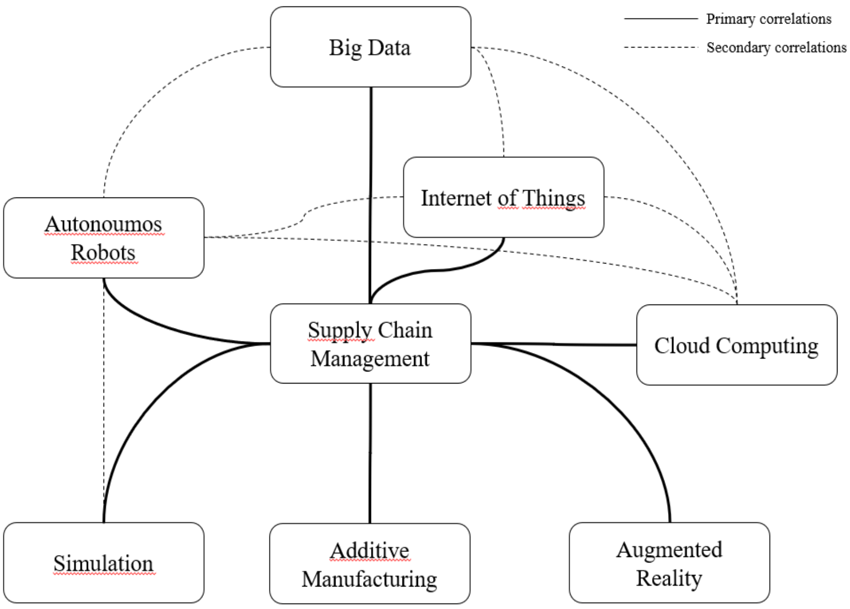

Figure 4 - Correlation of the root term to the linking ter.

Figure 4 shows primary correlations and secondary correlations. Primary correlations directly connect the root term with the linking term. Secondary correlations connect the linking terms between them.

The primary correlation between supply chain management and big data, autonomous robots, the internet of things, cloud computing, simulation, additive manufacturing, and augmented reality is strong. Each of these technologies has the potential to revolutionize the way supply chains are managed, and each is already having a significant impact on the field.

Big data and analytics are providing supply chain managers with new insights into their operations. Autonomous robots are taking over many of the tasks formerly performed by human workers, increasing efficiency, and reducing costs. The internet of things is making it possible to track assets and inventory in real time, while cloud computing is providing the computing power needed to manage ever-larger data sets. Simulation is helping managers to plan and optimize their supply chains, while additive manufacturing is reducing the need for inventory and increasing the flexibility of manufacturing operations. Finally, augmented reality is providing a new way for managers to interact with and understand their supply chains. Each of these technologies is having a major impact on supply chain management, and the combination of all of them is resulting in a major transformation of the field.

Related to secondary correlation, topics such as cloud computing, internet of things, big data and autonomous robots are connected to each other, thus generating a greater scope of application of these elements. The use of big data, autonomous robots, the internet of things, and cloud computing can all be beneficial for supply chain management. By using these technologies together, businesses can create a more efficient and effective supply chain. Big data can be used to gain insights into customer behavior and trends, which can help businesses to make better decisions about their products and services. Additionally, autonomous robots can help to automate tasks and improve efficiency, while the internet of things can be used to track goods and monitor conditions. Finally, cloud computing can provide a scalable and flexible way to store and access data. The application of simulation, autonomous robots, and SCM is a very promising area. These technologies can be used together to optimize the performance of existing supply chain systems and to design new ones from scratch. For example, simulation can be used to study the impact of different factors on the performance of supply chain systems and to find the optimal parameter values for these factors. This can improve the efficiency of the supply chain and reduce the cost of labor. In addition, autonomous robots can also be used to monitor the status of the inventory and to automatically reorder inventory when it is running low.

In addition, the elements additive manufacturing and augmented reality are not connected to any other element, evidencing that there are gaps to be explored to increase connectivity with other elements. The use of additive manufacturing in SCM is still in its early stages, but there are several potential applications that have been identified. One area where AM could have a major impact is around spare parts and inventory management. Traditionally, companies have had to maintain large inventories of spare parts to be able to meet customer demand. However, with additive manufacturing, companies would be able to produce spare parts on-demand, which would greatly reduce the need for large inventories. Additionally, additive manufacturing could be used to produce customized products. This would allow companies to respond quickly to customer demand without the need to maintain large inventories of finished goods.

Related to augmented reality, there are several benefits that can be gained from using augmented reality in SCM. First, augmented reality can provide real-time information about the location and status of inventory, which can help to improve inventory management and reduce the need for manual inventory checks. Second, augmented reality can be used to visualize data about the supply chain, such as transportation routes, to help managers, make better decisions about where to ship goods and how to optimize the supply chain. Finally, augmented reality can be used to provide instructions and information to workers in warehouses and distribution centers, which can help to improve worker productivity and accuracy. Despite the potential benefits of augmented reality in supply chain management, there are also some challenges that need to be addressed. First, augmented reality technology is still in its early stages of development, and there is a lack of standardization among different augmented reality platforms and devices. This can make it difficult for companies to implement augmented reality solutions across their supply chains. Second, augmented reality solutions can be expensive, and they may require specialized hardware and software. Finally, augmented reality solutions may require special training for workers to be used effectively.

Mechanisms for inclusion identified

From content analysis, it was possible to identify the mechanisms that promote the inclusion and promotion of elements of industry 4.0 in the SCM. Mechanisms are processes in concrete systems, whether physical, social, technical, or of some other kind (Bunge, 2004) and they can be classified as systems, models, methods, techniques, or tools. The main difference between a mechanism and an element of industry 4.0 is the interaction. An element is only an isolated concept, and a mechanism is a group of elements or parts that interact together. To classify these mechanisms, the conceptual definitions presented by (Eidelwein et al., 2016) were used. Table 8 shows all mechanisms identified from the reading of articles and the respective elements that relate to the mechanism.

Table 8 - Mechanisms identified.

Mechanism identified	Element identified
RFID Supply Chain Architecture in Cloud Environment, Cloud Supply Chain Network, SCLOUDY	Cloud computing
Inter-organizational collaborative simulation, Hierarchic Structure, Gradient-based, Statistical-based, Meta-model-based e Meta-heuristic	Simulation
Logistic cloud	Internet of Things, Cloud Computing
Big Data Architecture	Big Data
Smart Object Framework	Internet of Things
Cloud Robotics Architecture	Autonomous robots, cloud computing

Cloud of Things	Internet of Things, Cloud Computing,Big Data
Sectionalized Motion Control, Routing Optimization	Autonomous robots

Among the mechanisms identified for the element cloud computing, the following stand out: RFID Supply Chain Architecture in Cloud Environment, Cloud Supply Chain Network and SCLOUDY. The mechanism RFID Supply Chain Architecture in Cloud Environment is a tool that aims to integrate the use of RFID with a cloud data storage networks, ensuring information safety through authentication protocols, properties and transfers (Lin et al., 2015). The Cloud Supply Chain Network's main function is to integrate two or more parts of a supply chain network by sharing cloud information, thus contributing to the management of stakeholder information (Gowda and Subramanya, 2016). The SCLOUDY is a model that aims to understand request flows between different links in the chain, contributing to establish a collaborative flow between the parties involved (Carrillo and Franky, 2014).

For the element Big Data, the following mechanism stands out: Big Data Architecture. Big Data Architecture is a model that guides development flows for building an integrated system using Big Data in order to analyze and manage large volumes of data from a supply chain (Biswas and Sen, 2016). The framework proposed by Bisway and Sen (2016) uses several data sources, such as suppliers, manufacturers, warehouses, among others. This model receives structured and unstructured data.

The only unique mechanism identified from the element internet of things is Smart Object Framework. The Smart Object Framework mechanism aims to integrate objects and sensor data. It is supported by an architectural logic that guarantees the fusion of independent data flows (Sánchez López et al., 2012).

Among the mechanisms identified, Sectionalized Motion Control and Routing Optimization aim to integrate or promote the use of autonomous robots in SCM. The Sectionalized Motion Control is a method that considers several characteristics of an AGV, such as different stages of movement, energy control and predictive control of displacement (Yin and Zhao, 2013). According to Yin and Zhao (2013), it is possible to optimize the speed of movement using energy consumption and displacement stability using this method. Routing Optimization is a technique that seeks to optimize the performance of intelligent vehicles, that is, it defines an optimal or approximate route to achieve the lowest parameter of time and displacement (Zhou et al., 2014).

The mechanisms identified for the simulation element are Inter-organizational collaborative simulation, hierarchic structure, gradient-based, statistical-based, meta- model-based and meta-heuristic. Inter-organizational collaborative simulation is a model to analyze complex supply chain networks by integrating knowledge about agents, flows and methodologies. It is a collaborative representation of this knowledge (Long, 2017). The hierarchic structure mechanism is a simulation technique that aims to structure, through logical steps, certain problems (Straka et al., 2018). In SCM, according to Straka et al. (2018), this technique may contribute to the study of large-scale logistics systems, thus contributing to a fast understanding of the problem to be addressed.

The gradient-based, statistical-based, meta-model-based and meta-heuristic mechanisms are simulation techniques that contribute to the inclusion of the simulation element in SCM. The techniques may be used for different applications, such as inventory management, transport and logistics management, supply chain design, integration and collaboration (Arisha, 2010).

Among the mechanisms identified, there was Logistic Cloud. This mechanism is a model that promotes the integration of elements of the industry 4.0 internet of things and cloud computing. The model proposes the use of four layers of development aiming to assist in the design of internet-based logistics system projects and cloud computing (Chen et al., 2014).

Another mechanism identified was cloud robotics architecture, which allows integrating elements such as autonomous robots and cloud computing. This technique creates a cooperative system of data sharing and information collecting from different data sources. Thus, it allows an overview on the manufacturing environment (Cardarelli et al., 2017). This overview, according to Cardarelli et al. (2017), contributes to coordinate movements of autonomous robots in an optimized way, thus increasing the efficiency and flexibility of the movements of the equipment.

Finally, the cloud of things mechanism was identified. It associates the elements internet of things, big data, and cloud computing. Cloud of things is a system in which integration and

SCM platform happen within individual clouds, that is, there is a cloud for each link, such as storage cloud, logistics cloud, supplier cloud and client cloud (Yan et al., 2014). These clouds are supplied with information from the physical resources of the internet of things and are processed through big data analysis, thus providing solutions to improve supply chain performance (Yan et al., 2014).

Relations between the elements of Industry 4.0 and the SCOR model

In order to establish relations between the elements and the basic processes of the SCOR model, the categorical analysis was used. It allows the connection of a content with a respective code (Bardin, 2011). The first step to draw the relation between elements of industry 4.0 and the SCOR model was to categorize the presence or not of the elements in the selected studies. In this step, it is important to note that an article may contain more than one element, making the total number of categorizations different from the number of studies selected. This identification aims to guide the next step, i.e., establish the relations between the elements and the SCOR model. Figure 5 shows the identifications.

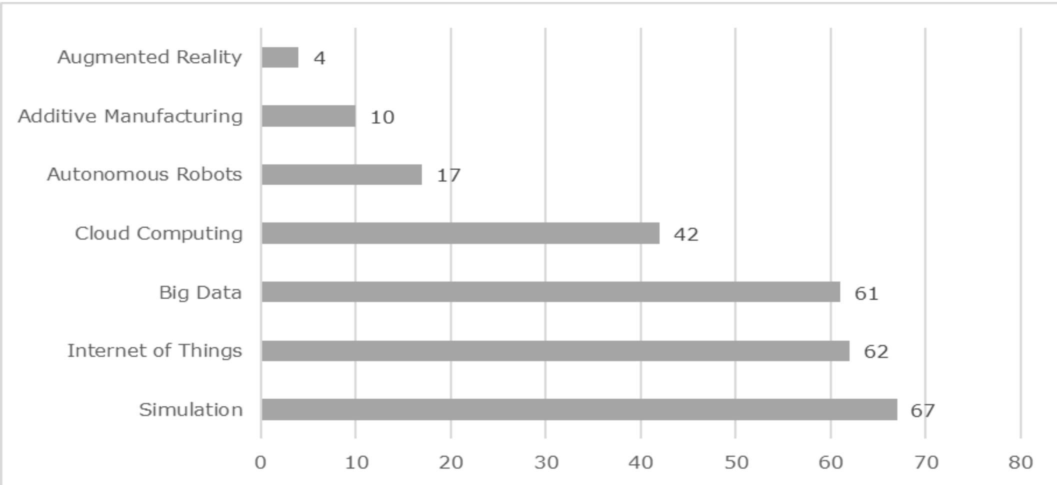

Figure 5 - Identification of the elements in the selected studies.

Figure 5 shows that the elements internet of things, simulation and big data were identified more than the other elements, representing 77% of the evidence. This high number of evidence was expected according to the map of keyword correlations presented in section four. In addition, this high number of identifications can be justified by the popularization of the terms internet of things and big data in recent years and by the various applications that the simulation has provided since its inception.

After the identification of the presence of the elements, they were categorized according to their contribution to the basic processes of the SCOR model. At this step, the elements may contribute to more than one process, contribute only once or not contribute at all, making the data sample different from the number of studies selected for analysis. The processes evidenced in the selected literature are shown in Figure 6.

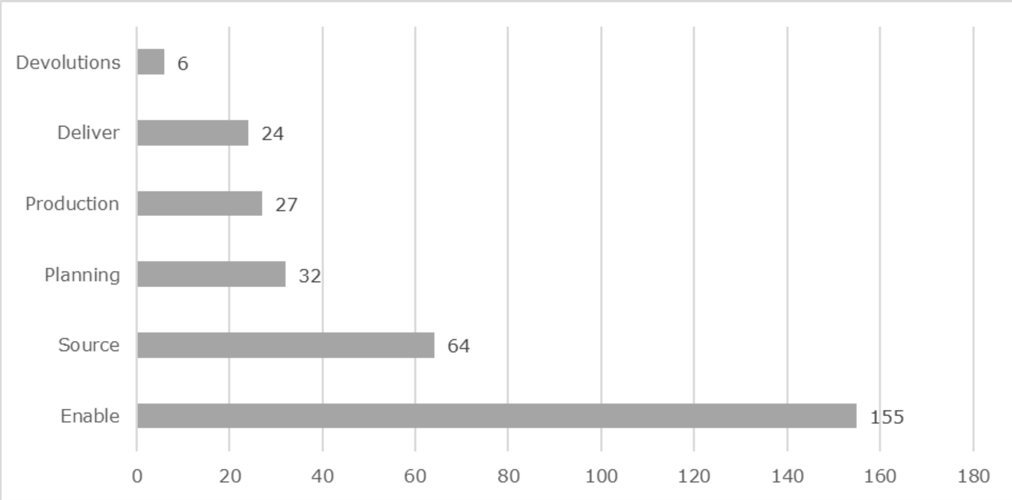

Figure 6 - Basic processes of the SCOR model identified in the selected studies.

According to Figure 6, the enable process of the SCOR model represents 50% of all categorizations. This value is related to the process characteristics and connectivity that industry 4.0 provides, in which the information flow is one of the key processes to establish such a connection (Szozda, 2017). In addition, all processes of the SCOR model were identified during categorizations. This is due to the heterogeneous characteristics that each element has.

The last step to materialize the relation of elements to processes of the SCOR model was to identify how each element of Industry 4.0 contributes to the basic processes of the model. Figure 7 shows the number of categorizations performed for each element of the industry 4.0.

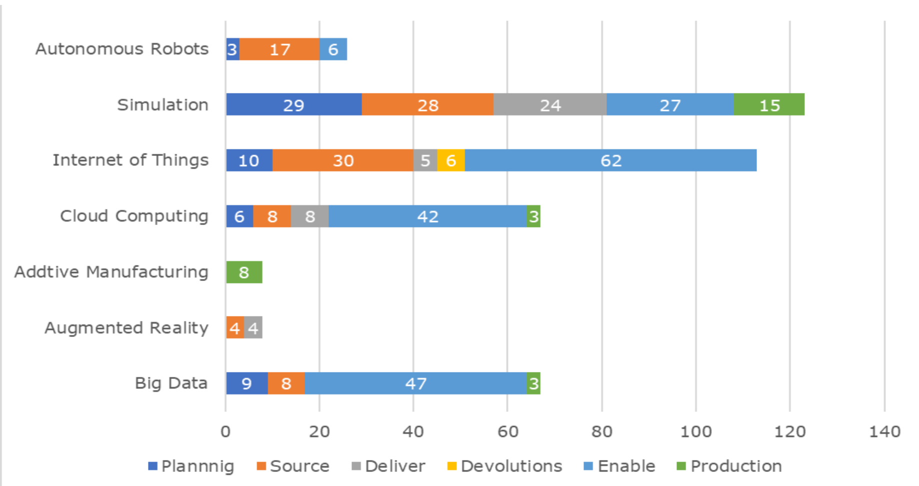

Figure 7 - Categorization of basic processes in each element of the industry 4.0.

Figure 7 explains the categorizations of the basic processes of the SCOR model in function of the elements of industry 4.0. This categorization presents the number of times an element of industry 4.0 has contributed to some of the basic processes of the SCOR, according to the analysis of the articles presented above. This information helps to draw relations between elements and processes.

From the relations established, it is possible to understand how each element contributes to the basic processes and which are the processes that are most evidenced in the literature. Through categorization, it was evidenced that Big Data acts in the processes enable, plan, source and make. It is more evident in the enable process. This is because this element has the capacity to gather and analyze datasets that aid decision-making, thus contributing to the operation of the supply chain. In addition, Big Data may contribute to agility and responsiveness criteria by virtue of the ability to consolidate information for decision-making.

The processes of actuation of augmented reality were source and deliver due to the contribution that augmented reality provides to the separation of materials and the servicing of orders. In addition, this element may contribute to the criterion of reliability since it assists in the assertiveness of the separation of materials.

Additive manufacturing acts only in the process make because this technology acts only in the process of manufacturing of items, as was explained by the identified contributions. In addition, this element may contribute to evaluation criteria responsiveness, agility and cost because of the possibility of manufacturing the material at the point of use.

The processes verified for cloud computing are enable, plan, return, and deliver. The most evidenced process was enabled due to the characteristic of integration between different links of the supply chain through digital platforms that aim to share data and information. Regarding the evaluation criteria, cloud computing may collaborate with agility and costs since information is available for all links in the chain through a single mechanism.

Internet of things acts in the processes of enable, source, plan, return and deliver, the most comprehensive being the process enable. As explained by the identified contributions, internet of things is responsible for generating data captured from different sources. These data contribute to the monitoring and maintenance of the operation of supply chains since they are transformed into information. Internet of things may cooperate with the evaluation criteria reliability, responsiveness, agility and costs. This is because internet of things provide data instantly at different points in the chain, such as inventory control, vehicle tracking etc.

The processes evidenced for the element simulation were enable, source, plan, deliver and make. This element acts more comprehensively in the process plan since, through simulations, it is possible to provide information that contributes to the structuring of the operation of the supply chain, as verified in the literature. Simulation may also contribute to the evaluation criteria agility, responsiveness, assets, reliability and costs, since it is used as a tool for decision-making. Many of such decisions aims to achieve one of these performance indicators.

Finally, the processes identified for the element autonomous robots were source, enable and plan. The source process was the most evidenced because this element performs transfer of materials in an autonomous way between different points of use. Likewise, autonomous robots cooperate with the evaluation criteria reliability, costs and assets. This is because this element operates autonomously within organizations by ensuring that the material transfer operation is performed safely and efficiently, as verified in the literature. Table 9 shows a synthesis of the elements with the respective processes in which they operate.

Table 9 - Synthesis of the elements with the basic processes of the SCOR model.

Element	Basic process of SCOR model
Autonomous robots	Enable, source, planning
Simulation	Enable, source, planning, deliver and production
Internet of Things	Enable, source, planning, deliver and return
Cloud computing	Enable, source, planning, deliver and production
Additive manufacturing	Production
Augmented reality	Source
Big Data	Enable, source, planning and production

Through this synthesis, it is possible to perceive that the elements in the industry 4.0 act within the basic processes of the SCOR model. However, it has been shown that some elements, such as additive manufacturing and augmented reality, contribute less expressively than other elements, thus demonstrating opportunities for further research. In addition, the return process needs to be further explored in relation to the elements since it was little evidenced in categorizations.

From the relationships identified, the enable process acts practically in all elements. This relation can be justified by connections between the elements autonomous robot, internet of things, big data and cloud computing, as observed in the contributions of the elements in the SCM. In addition, internet of things, big data and cloud computing are characterized by the use of data in their applications. Data becomes information that promotes the process enable within organizations.

In general, these relationships contribute to guiding the use of elements in each process of the SCOR model. Thus, it is possible to direct future applications in each process and to identify with which assessment criteria it will cooperate. Such targeting allows organizations to establish an appropriate management process to act in a dynamic context as established by the supply chain in which they operate.

CONCLUSION

This study established theoretical relations between the elements of industry 4.0 and SCM through a systematic literature review. These relations help to understand how each element is applied in the SCM and which the main contributions they provide. This allows an overview of the subject and the development of the theme within academy. In addition, from the identification of contributions, it was possible to draw relations between elements to explain how each element is connected to each other.

Through content analysis, it was identified and described which mechanisms promote or include the elements within the scope of the SCM. From the identification of these mechanisms, it was possible to understand how each element is inserted in the SCM, serving as guidance for managers to use such elements in the context of the supply chain. In addition, the identification and description of these mechanisms provide a knowledge of systems, models, methods, techniques, or tools existing in the analyzed literature.

Another contribution of this study was that it established relations between the elements of industry 4.0 and the basic processes of the SCOR model. These relations help to understand how each element is acting in the SCM and how they contribute to the supply chain assessment criteria. Moreover, such relationships may contribute to managers. They can use the elements within organizations in a targeted manner, acting specifically in processes whose evaluation criteria need to be developed. Such relationships serve as sources of information for future studies given the gaps that have been identified in section 5.3.

This study presents some limitations in terms of covering only one theoretical analysis on the concepts, that is, no real applications were made considering the topics addressed. Another limitation is considering processes of the SCOR model as categories of analysis, disregarding other models existing in the literature such as the model of the Ohio University proposed by (Lambert et al., 1998).

Finally, it is suggested as an agenda for future studies analyses of applications of elements considering the basic processes of the SCOR model and evaluation its criteria in the context of organizations by performing case studies. There is a lot of potential for future research on Industry 4.0 and Supply Chain Management. Some possible areas of focus could include: i) Investigating how Industry 4.0 technologies can be used to improve supply chain efficiency and effectiveness; ii) Examining the impact of Industry 4.0 on supply chain risk and resilience; (iii) Investigating how Industry 4.0 can be used to create more sustainable supply chains; (iv) Studying the impact of Industry 4.0 on employment and skills in the supply chain sector; and (v) Exploring the ethical implications of Industry 4.0 and Supply Chain Management.

Furthermore, as future opportunities, studies could address data safety and supply chain management. Information safety is fundamental in collaborative networks (Lee and Kwon, 2016), and the elements of industry 4.0 are directly related to data and information flows. In addition, further research could develop horizontal and vertical integration mechanism systems in SCM, since this topic was not yet explored by the analyzed literature.

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