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SUPPLY CHAIN CONTROL TOWER: DEFINITIONS AND GAPS BETWEEN LITERATURE AND APPLICATION IN INDUSTRIES

Joinville
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Work presented as a requirement for obtaining the Bachelor's degree in the Graduate Course in Transport and Logistics Engineering at the Technological Center of Joinville, Federal University of Santa Catarina.

Advisor: Dra. Francielly Hedler Staudt

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Final Paper submitted as a requirement to obtain a bachelor's degree in the Graduate Course of Transport and Logistics Engineering of the Joinville Technological Center of the Federal University of Santa Catarina.

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“I learned that courage is not the absence of fear, but the triumph over it. The brave man is not the one who is not afraid, but the one who conquers that fear.” (Mandela, 1995).

RESUMO

Impulsionado pelos avanços da Indústria 4.0, o setor global de manufatura está gradualmente incorporando tecnologias como inteligência artificial e plataformas digitais para aprimorar a resiliência da cadeia de suprimentos. No entanto, muitas empresas ainda estão nos estágios iniciais de conectar perfeitamente toda a sua cadeia de valor. Sistemas de gestão desempenham um papel fundamental nessa transformação digital, facilitando a adaptação às demandas da Indústria 4.0. Dentro desse contexto, a Torre de Controle da Cadeia de Suprimentos (TCCS) surgiu como uma solução tecnológica fundamental que oferece visibilidade, coordenação e otimização em tempo real ao longo da cadeia de suprimentos. Portanto, este trabalho tem como objetivo apresentar a definição da torre de controle da cadeia de suprimentos com as tecnologias e requisitos associados, contrastando essas descobertas com três projetos de TCCS em grandes empresas. Para alcançar esse objetivo, foi realizada uma revisão sistemática da literatura utilizando o método PRISMA. Além disso, o trabalho também aplica a metodologia estudo de caso, para reunir informações sobre projetos de torre de controle em cadeia de suprimentos de empresas. Uma análise bibliométrica e bibliográfica é conduzida com um portfólio de 19 artigos. A pesquisa identifica lacunas entre a literatura e as aplicações práticas e propõe um framework para a implementação bem-sucedida da TCCS com base na literatura. Os requisitos necessários para se ter uma torre de controle de cadeia de suprimentos de sucesso incluem contemplar tecnologias como ERP, WMS, Tecnologia aplicada a nuvem, IoT, Big Data e Machine Learning. Integra áreas como Compras, Planejamento de Materiais e Demanda, Transporte Inbound e Outbound, Manufatura, Armazenagem e Atendimento ao Cliente. Tem a funcionalidade final de fornecer Visibilidade, Colaboração, Monitoramento, Tomada de Decisão, KPIs, Gestão de Riscos, Controle de Custos e dar Alertas para evitar possíveis riscos. E, por último, toma decisões em todos os níveis: estratégico, tático e operacional.
Palavras-chave: Logística. Cadeia de Suprimentos. Torre de Controle. PRISMA. Torre de Controle da Cadeia de Suprimentos.

ABSTRACT

Driven by the advancements of Industry 4.0, the global manufacturing sector is gradually incorporating technologies such as artificial intelligence and digital platforms to enhance supply chain resilience. However, many companies are still in the early stages of seamlessly connecting their entire value chain. Management systems play a key role in this digital transformation, facilitating adaptation to the demands of Industry 4.0. Within this context, the Supply Chain Control Tower (SCCT) has emerged as a fundamental technological solution that provides real-time visibility, coordination, and optimization throughout the supply chain. Therefore, this paper aims to present the definition of the supply chain control tower with associated technologies and requirements, contrasting these findings with three SCCT projects in large companies. To achieve this goal, a systematic literature review was conducted using the PRISMA method. Additionally, the paper also applies the case study methodology to gather information about supply chain control tower projects in companies. A bibliometric and bibliographic analysis is conducted with a portfolio of 19 articles. The research identifies gaps between the literature and practical applications and proposes a framework for the successful implementation of SCCT based on the literature. The necessary requirements for a successful supply chain control tower include embracing technologies such as ERP, WMS, Cloud Technology, IoT, Big Data, and Machine Learning. It integrates areas such as Procurement, Material and Demand Planning, Inbound and Outbound Transportation, Manufacturing, Warehousing, and Customer Service. It has the ultimate functionality of providing Visibility, Collaboration, Monitoring, Decision Making, KPIs, Risk Management, Cost Control, and issuing Alerts to avoid potential risks. Lastly, it makes decisions at all levels: strategic, tactical, and operational.
Keywords: Logistics. Supply Chain. Control tower. PRISMA. SCCT.

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LIST OF ACRONYMS

BI - Business Intelligence
CLM – Logistics Management Council
CRM – Customer Relationship Management
CT – Control Tower
ETD – Estimated Time Delivery
ETA – Estimated Time Arrival
ETL – Extract, Transform, Load
E2E – End-to-End
EDI – Electronic Data Interchange
ERP – Enterprise resource planning
FMCG – Fast-Moving Consumer Goods
4IR – Fourth Industrial Revolution
GPS – Global Positioning System
GPRS – General Packet Radio Service
IT – Information Technology
IoT – Internet of Things
KPI – Key Performance Indicator
LCT – Logistics Control Tower
MFCT – Master Facilitative Control Tower
PRISMA – Preferred Reporting Items for Systematic Reviews and Meta-Analyses
QR CODE – Quick Response Code
RFID – Radio-Frequency Identification
SAAS – Software as a Service
S&OE – Sales and Operation Execution
S&OP – Sales and Operational Planning
SC – Supply Chain
SCCT – Supply Chain Control Tower
SCM – Supply Chain Management
SCT – Service Control Tower
SME's – Small and Medium Businesses
TCT – Transportation Control Tower
TMS – Transportation Management System

WMS – Warehouse Management System

YMS – Yard Management System

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1. INTRODUCTION

Transportation management involves the connection between many areas of a company's supply chain, and therefore, synergy between processes and efficient communication through electronic means are crucial (Ballou, 2006). The introduction of Information Technology (IT) in business operations is drastically changing the way supply chains work, improving collaboration, trust, and commitment among chain members (Goettems *et al.*, 2019).

Information Technology plays a crucial role in supply chain efficiency, leveraging high-quality data and tools to assist in operational tasks such as yard and fleet management, delivery tracking, and overall transport management (Oliveira et al., 2021). Aguiar, Magalhães, and Lima (2023) emphasize that the evolution of information technology enables greater agility in processes, leading to cost reduction, enhanced security, mitigating challenges in transport management, and improving customer satisfaction.

In this context, control towers have been seen as the next tool to monitor supply chains (Aliás *et al.*, 2015). However, most companies are still in the early stages of their efforts to connect the entire value chain with a seamless flow of data (Malmstedt; Backstrand, 2022). This can happen for a lot of reasons, such as the lack of reliable data sources, convenience of current processes, multiple non-correlated information bases, and the lack of integrated systems.

Visually a control tower should present information in a simple manner, with relevant graphical analysis and a design that is easy for employees to understand (Aliás *et al.*, 2015; Patsavellas; Kaur; Salonitis, 2021). Additionally, Rodrigues (2020) argues that the control tower should support the business with tactical and operational knowledge for logistics centralization, scheduling, monitoring and tracking shipments, promoting performance measurement with continuous improvement.

Therefore, the pursuit of reducing costs associated with the materials and product distribution sector must be aligned with the production process and quality of each organization. The study of implementing a control tower is important for reducing waste in the logistics chain.

In this perspective, this study aims to define supply chain control tower, the technologies used and the main requirements for implementation. Furthermore, a comparison will be made between what is found in the literature versus what some companies understand as SCCT. Finally, it is built a new framework presenting the requirements to implement a SCCT.

The study is described as follows. After the introduction and definition presented in this Chapter, Chapter 2 presents the work methodology and the steps conducted in the systematic literature review. The content analysis, Chapter 3, defines the advances in supply chain management and technologies applied in supply chain. Also defines what is a supply chain control tower and technologies present. The work highlights the functionalities of a Supply Chain Control Tower such as real-time tracking, improved decision-making, inventory optimization, demand forecasting, and risk management. Case studies examples demonstrate how different organizations have harnessed the power of control towers to streamline their logistics operations.

1.1. Objectives of the study

The general objective of this work with its specific objectives are presented below.

1.1.1. Main Goal

To define supply chain control tower based on a systematic literature review, identifying the gaps between the literature and application in industries.

1.1.2. Specific Goals

- To establish based on a systematic review what is known about Supply Chain Control Towers (SCCT).
- To identify the technologies used in SCCT.
- To recognize which areas and functionalities should be present in a SCCT.
- To compare the literature and the control towers present in the companies interviewed.
- To establish successful requirements to implement a SCCT.

1.2. Motivation of the work

As highlighted by Verna, Koul, and Singh (2020), the global industry is gradually incorporating advanced technologies to strengthen supply chain network. However, as mentioned by Souza and Zhou (2015), many companies are still in the early stages of integrating their entire value chain.

In this context, the SCCT emerges as a fundamental technological solution, providing visibility, coordination, and optimization across the supply chain, as emphasized by Alias et al. (2015). However, there is evidence of a gap between theory and practice in the literature and real-world applications of the SCCT in companies as found by the author. Creating the need for a more in-depth investigation.

This gap between theoretical conception and practical application is particularly intriguing and underscores the need for a more in-depth investigation which will be presented in this paper. The justification for this final work lies in the importance of understanding the success requirements implementation of the Control Tower.

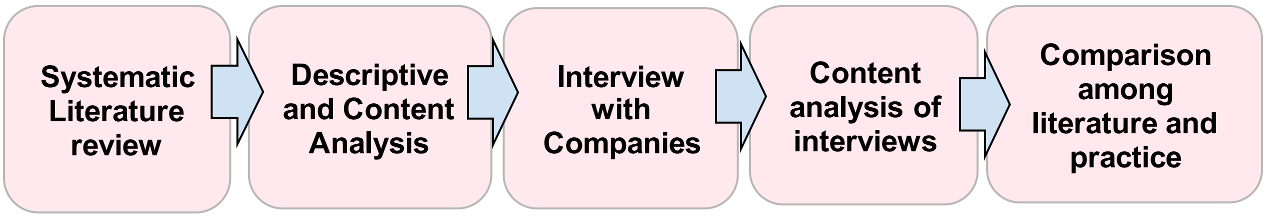
2. METHODOLOGY

2.1. GENERAL METHODOLOGY

This study can be categorized as theoretical research, employing a qualitative and quantitative approach throughout a systematic literature review. It is also classified as a case study with observations and interviews based on Berto and Nakano (1998). The aim is to analyze the concept of supply chain control tower in the literature and compare it with some projects performed in companies.

The research is conducted according to the flowchart shown in Figure 1.

Figure 1 – General work Steps



Source: Author (2023).

Initially, a systematic literature review was conducted to gather relevant articles, aiming to form a comprehensive understanding of the subjects under study. The work applies the Prisma methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Moher *et al.*, 2009), detailed in section 2.2, to define the article portfolio.

In section 2.3, a descriptive analysis was performed on the identified articles. Following this, a field study was undertaken, involving interviews with companies that have implemented the control tower. The questionnaire applied for is present in Annex A. Seven companies known to the author and her advisor were contacted. One did not have a control tower implemented and three didn't answer the questions, leaving only three companies interested in participating and providing data for this study. The companies are described in this study as A, B, and C. The conversations took place on different dates from august to september 2023 and the questionnaire used is presented in section 4 with content analysis of the interviews. The interviews took place with four people, which two were from the same company. The profile of each one can be seen in table 2.

Table 1 - Profile of the Interviewees

Team Member	Company	Positions in CT	Role	Experience in SCM
Respondent 1	A	CT Specialist	Logistics Operations Manager	15 years
Respondent 2	B	Materials planning analysis	PCM Analyst Jr	2 years
Respondent 3	C	Transport analysis	Transport Analyst Jr	2 years
Respondent 4	C	Forecast analysis	S&OP Intern	1 year

Source: Author (2023).

Respondent 1 underwent two interviews: one conducted online and the other in person. This approach afforded the author a real-time observation of the control tower. The interview with Company B was also personal and it was possible to visit the tower. Additionally, an interview was conducted with one of the tower's employees, identified as respondent 2. Respondents 3 and 4 were interviewed at different times each sharing insights into their respective interactions with the control tower.

Finally, based on the articles found in the literature and the content analysis of the interviews a comparison with both is presented in section 5. The comparison was made in a theoretical way, addressing themes found in the literature that were not mentioned in the literature.

2.2. SISTEMATIC LITERATURE REVIEW - PRISMA METHODOLOGY

The PRISMA method was developed by Moher *et al.* (2009) and consists of a minimum set of evidence-based items for reporting systematic reviews and meta-analyses. It provides guidelines for the preparation of reports that assess the effects of interventions and other aspects, such as etiology, prevalence, diagnosis, or prognosis. This methodology is valuable in assisting researchers in conducting systematic reviews of published documents (Liao *et al.* 2017).

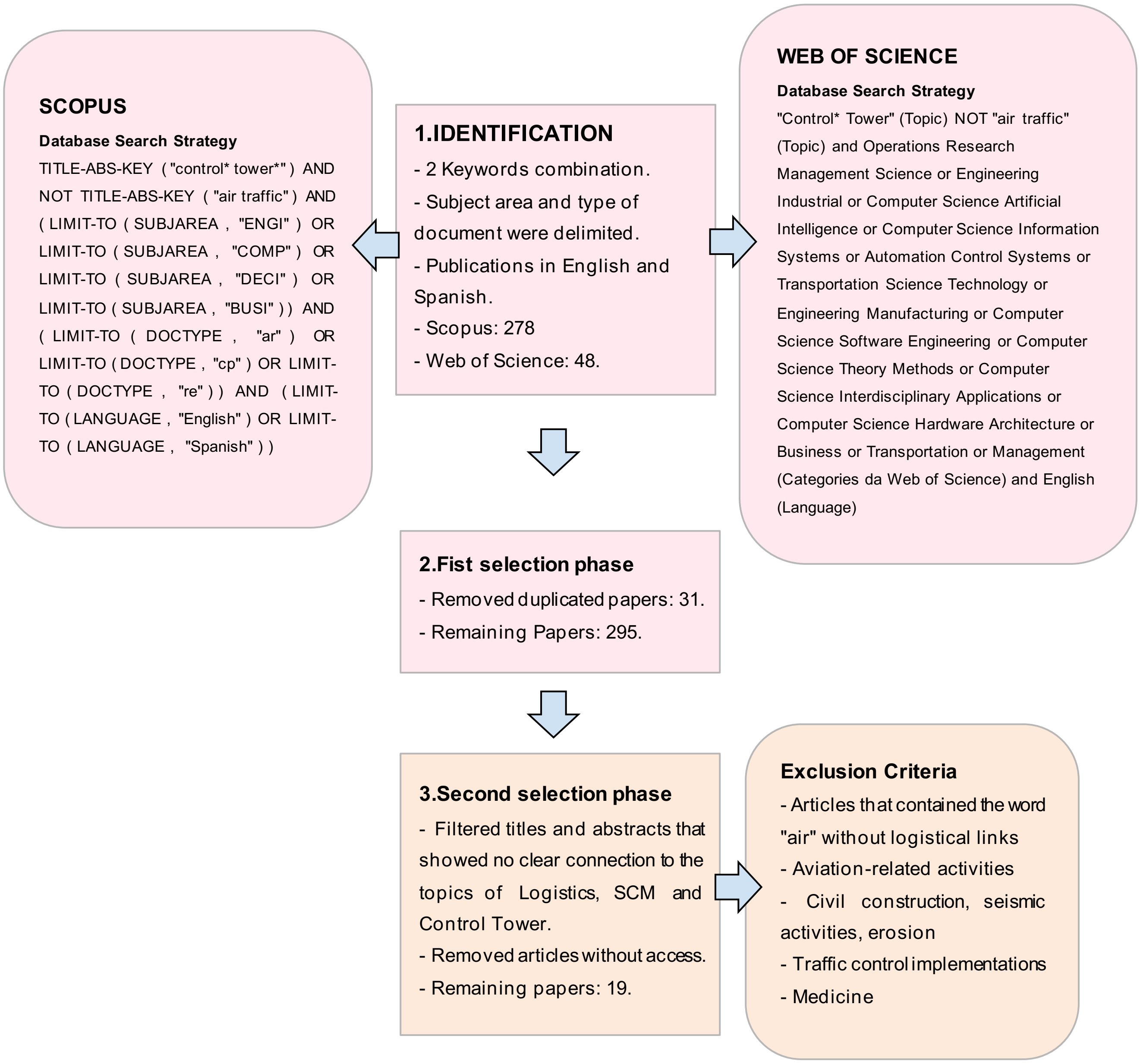
Moher *et al*. (2019) presents the PRISMA method through a four-steps flowchart. The first step refers to the identification of articles through the chosen databases. The second step is responsible for removing all duplicate articles. In the third are the filters carried out such as reading titles, abstracts, and the full text to identify whether the article is eligible or not. Finally, the articles that will be included in the quantitative analysis are presented.

In this study, PRISMA steps are performed to define the final portfolio. However, the flowchart presented in Figure 2 outlines just the main steps taken until the last article portfolio. Steps 2, 3 and 4 are presented together. To conduct this research, it was chosen to use the databases Scopus and Web of Science, based on the following criteria:

- These databases provide a vast collection of information, including abstracts, articles, and publications from a lot of journals and newspapers, many of which are freely accessible and contain most of the relevant articles in the field.
- The author's affiliated institution has access to the Capes system through a Brazilian government program.
- The Scopus database was also chosen because it only contains peer-reviewed articles.

To initiate the research, a careful selection of keywords was made to ensure alignment with the research topic in both databases. The search strategy employed involved using the keyword "Control* Tower," with the term "Control*" followed by an asterisk to capture articles with word variations. Additionally, a restriction is applied to exclude articles containing the term "air traffic". This decision is driven by preliminary exploratory research, which revealed a significant number of articles primarily focu sed on air control towers. Given that the study's objective is to investigate supply chain control tower, it is decided to narrow the scope of the literature review, ensuring a more targeted examination of the subject of interest.

Figure 2 - Article selection process based on PRISMA



Source: Author (2023).

Through the search strategy employed in both databases, a total of 326 results were initially identified. Step 2 involved eliminating duplicate articles found in both databases using Excel as a tool, resulting in the removal of 31 articles.

During this process, it became apparent that several remaining article titles were not relevant to the scope of the study. To ensure precision, a further round of filtering was conducted as shown step 3, excluding articles whose titles and abstracts showed no clear connection to the topics of Logistics, SCM and Control Tower. As a result, 247 articles were excluded from the research. Subsequently, an assessment was made regarding article availability, leading to the removal of 18 publications that either lacked free access or complete content.

The last filtering step involves carefully reviewing the full text of the remaining articles. As a result, 11 articles were identified that did not align with the research theme. They had relationship with Supply chain but without connection to the control tower leading to their exclusion from the study. This step ensured that only relevant and pertinent articles were included in the final analysis. By applying these filters, a preliminary portfolio of 19 publications closely aligned with the research theme were established.

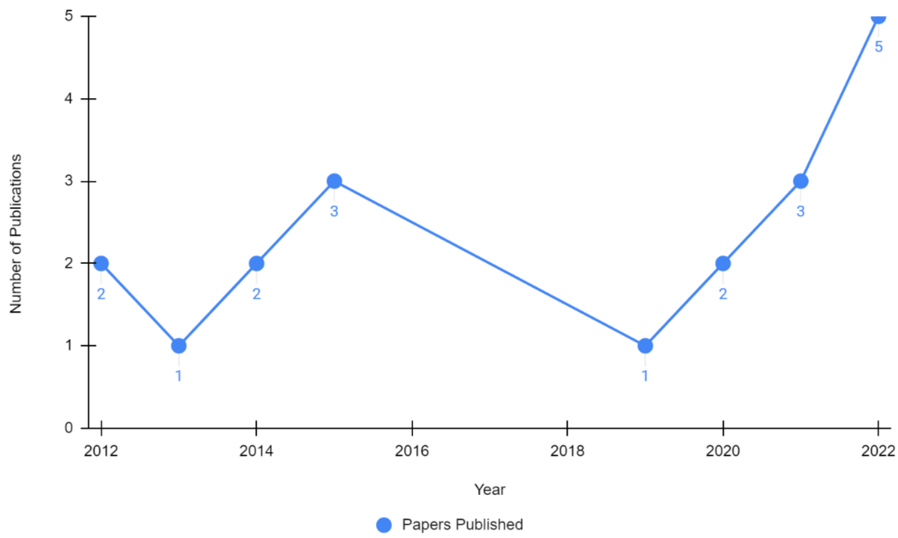
Carrying out the systematic review was essential to find articles focused on the control tower topic. Although only 19 articles were found, this shows how new the topic is still in the literature.

2.3. Descriptive Analysis of the portfolio

Three different analyses are performed to collect descriptive data from the portfolio: number of papers published per year (Figure 3), number of citations per paper (Figure 4) and papers published per journal (Figure 5).

Regarding the number of papers published per year, data reveals a variation in the number of papers published over the period from 2012 to 2022. The production of papers had a gradual increase from 2012 to 2015, reaching a peak of 3 papers in 2015. However, there was a decrease in the subsequent years, with a minimum of 1 paper published in 2019, followed by a slight recovery in 2020 and a significant increase in 2021 and 2022, reaching a peak of 5 papers in 2022. An explanation for this gap between years may be due to the articles referring to the period from 2012 to 2015 focusing more on the definition of logistical control tower as presented by Alias et al. While those published in recent years focus more on supply chain control towers such as Verna, Koul, Singh (2020) and Sharabati, Al-Atrash, Dalbah (2022).

Figure 3 – Papers Published per Year

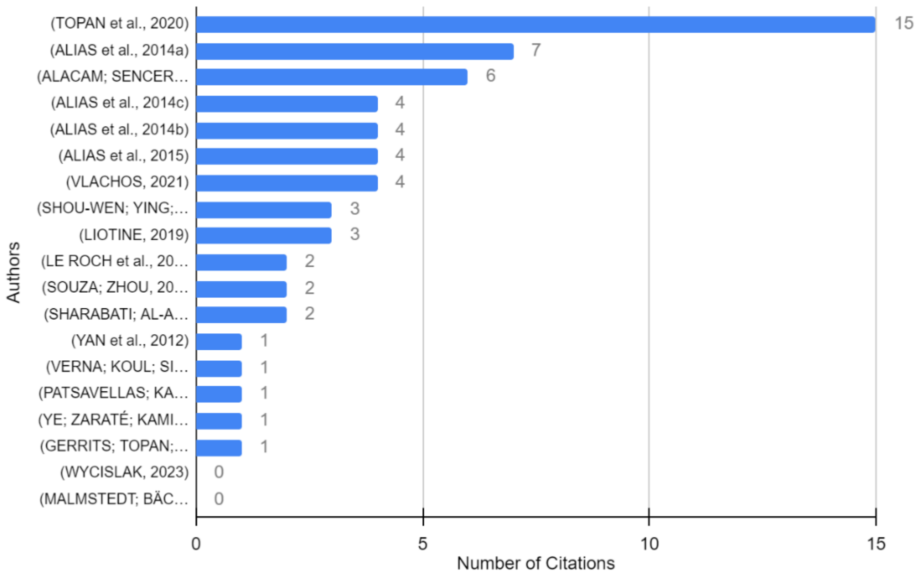


Source: Author (2023).

According to Figure 3, the topic is relatively new and has started to be discussed recently.

Figure 4 shows the result of the citation per article. This information was extracted from Scopus and Web of Science databases.

Figure 4 – Citations per article.

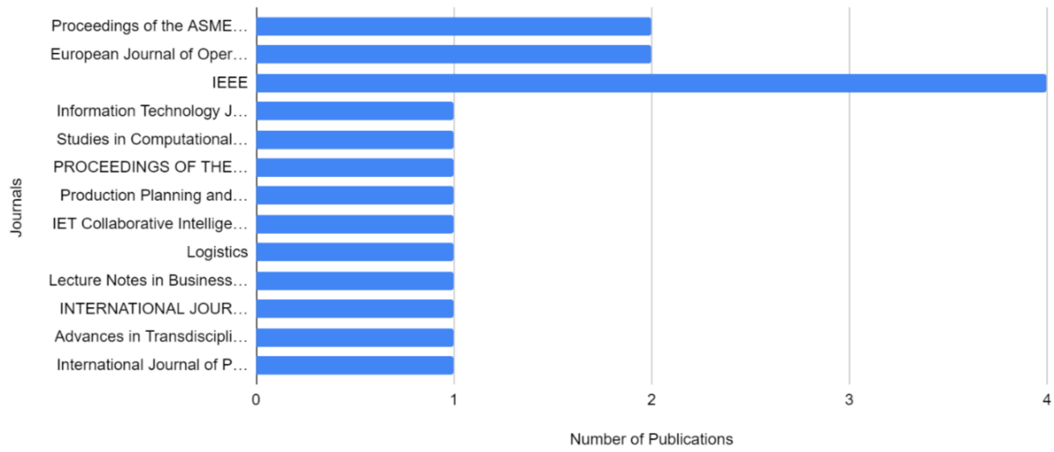


Source: Author (2023).

Topan *et al*. (2020) is the most cited author, with a total of 15 citations since 2020. Another example is Alias et al, who publishes more articles in this area (4), but the articles are from 2014 and 2015 without so many citations as Topan et al. 2020. This suggests that the work of this author is widely recognized and influential in the research field.

Finally, Figure 5 shows a diverse distribution of publications across sources, including conferences and journals. Notable sources such as IEEE, European Journal of Operational Research, and Proceedings of the ASME Design Engineering Technical Conference stand out, indicating a diversified and quality-oriented approach to sources.

Figure 5 – Papers Published per Journal



Source: Author (2023).

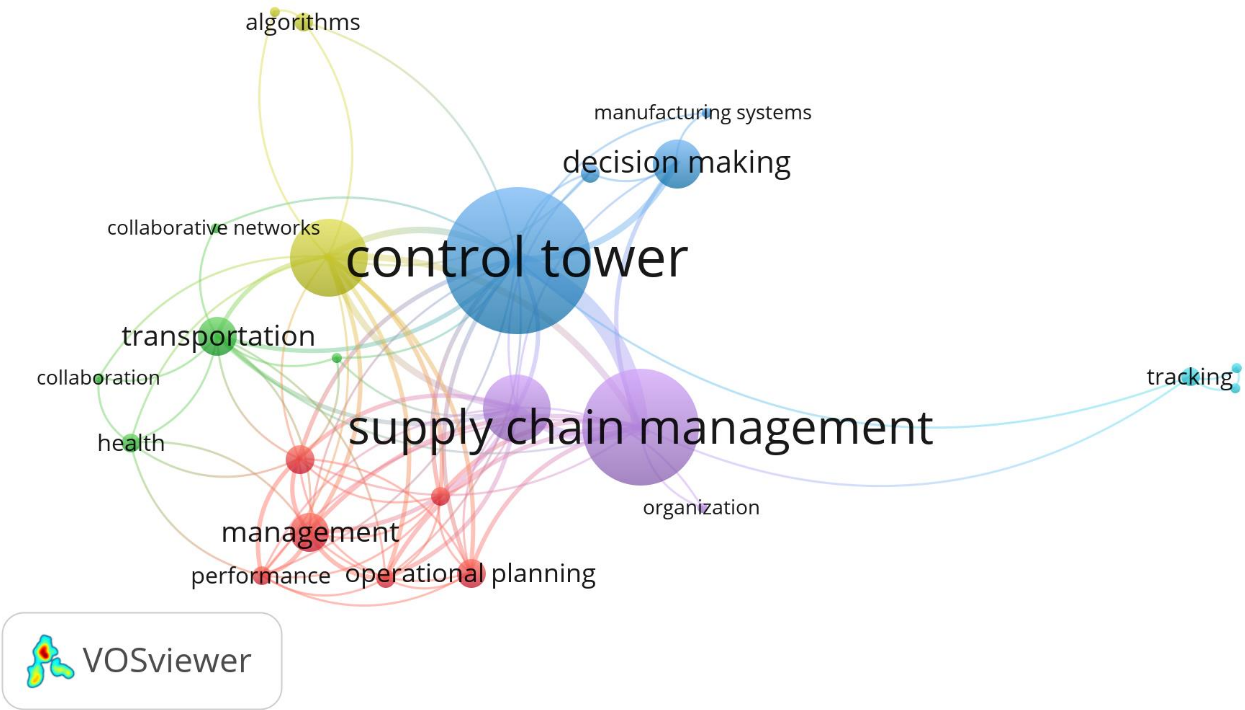
2.3.1. Word Cloud

During the process of selecting the publications retrieved from both databases, the VOSviewer tool is used for quantitative analysis to identify the primary keywords present in the scientific documents.

According to the Leiden University (2023), VOSviewer is a software designed to construct visualizations of bibliometric networks. This powerful tool allows for the input of many types of documents, including journals, articles, and conference papers, and enables the filtering of terms that commonly appear across the scientific files. Additionally, it facilitates the identification of patterns by considering shared authorship, journals and individual publications.

In order to employ VOSviewer, the publications from both databases are merged using an .ris file, and the keyword scope is further refined by replacing similar words in an Excel file. Figure 6 presents the cloud of keywords found through the filtered publications.

Figure 6 - Word Cloud.



Source: Author (2023).

The word cloud reveals that the term "Control Tower" is considered the strongest, followed by "Supply Chain Management," "Supply Chain," and "Logistics." This indicates the connection of these areas with the focus of the study.

The word cloud resulted in six clusters consisting of 24 keywords, which are as follows:

- Cluster 1 (red): digital information, industry 4.0, innovation, management and performance;
- Cluster 2 (green): business model canvas, collaboration, collaborative networks, health and transportation;
- Cluster 3 (blue): control tower, decision making, information, manufacturing systems;
- Cluster 4 (yellow): algorithms, IA, supply chain;
- Cluster 5 (purple): logistics, organization, supply chain management;
- Cluster 6 (light blue): service level indicators, service level management and tracking.

The clusters represent sets of items within a map, and each item is exclusively associated with a single cluster. The largest cluster, depicted in blue on the map, encompasses the primary keyword of the study linked to "decision making," "information," and "manufacturing systems." The second-largest cluster pertains to "Supply Chain Management," connected with "logistics" and "organization." All identified keywords offer a rapid and intuitive insight into the most pertinent themes, aiding in the selection of topics for the content analysis detailed in Section 3.

3. CONTENT ANALYSIS

3.1. ADVANCES IN SUPPLY CHAIN MANAGEMENT

According to the definition proposed by the Council of Supply Chain Management Professionals (CSCMP, 2004):

> Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. It also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers.

Bhosle *et al* (2011) comments that with the advancement of globalization, supply chain management has become more complex, largely due to the countless strategies that companies adopt to cover new markets, to seek supplies of raw materials low cost and the construction of plants in locations where the market is concentrated.

SCM is considered as a driver for almost all corporations to be able to compete successfully in the current dynamic and complex business environment (Sharabati at all, 2020). Another point that influences this complexity is the outsourcing of functions that are not related to the core business. Moreover, companies seek better profit margins reducing their operating costs (Bhosle *et al*, 2011). Ballou (2006) says that SCM encompasses the integration of activities and information related to the flow of transforming goods from the stage of raw material extraction to the end consumer, resulting in competitive advantages in the market. SCM help managers develop plans, conduct feasibility studies and pilots, collaboration, and build strategic alliances to unlock value from real-time visibility (Wycislak, 2023) .

Industry 4.0 and supply chain 4.0 come for basically orient to the use of mechanization, automation, Internet of things (IoT), and decision software aided tools (Patsavellas; Kaur; Salonitis, 2021). Under the trend of globalization, companies need to open markets, purchase raw materials worldwide, produce overseas, and to different countries in order to reduce costs and expand profits (Ye; Zaraté; Kamissoko, 2022). By those arguments it is important to obtain an online way to visualize the end-to-end supply chain activities. Some of these technologies are presented in the next section.

3.2. TECHNOLOGIES APPLIED IN SUPPLY CHAIN

During the most recent time, mainly due to Industrial 4.0 (4IR) advance, global manufacturing has just begun to adopt a range of technologies such as artificial intelligence and digital platforms to enable a more resilient supply chain (Le Roch et al., 2014; Malmstedt; Backstrand, 2022). Most companies are still in the early stages of their efforts to connect the entire value chain with a seamless flow of data. The use of management systems plays a crucial role in driving digital transformation and enabling companies to adapt to the demands of Industry 4.0 (Le Roch *et al.* 2014).

In the dynamic world of global manufacturing, 4IR technologies can facilitate the implementation of cyber-physical integration across the borders of an organization, deep into its supply chain (Patsavellas; Kaur; Salonitis, 2021). Information and Communications Technology (ICT) innovations are transforming businesses by providing better connections through mobile and web technologies and generating smarter decisions with data analytics (Alacam; Sencer, 2021). Digitalization can deliver major benefits to efficiency and transparency that are yet to be fully realized (Malmstedt; Backstrand, 2022). Therefore, digitization of supply chains requires intelligent long-linked technologies such as cloud services systems and IoT to replace technologies like Electronic Data Interchange (EDI) which focus on daily transactions (Vlachos, 2021).

Both large enterprises and Small and Medium Businesses (SMEs) are embracing various system types to maintain information quality and adapt to the industry 4.0 era. This adoption is driven by the need to enable digital transformation and meet the demands associated with Industry 4.0 (Le Roch *et al.,* 2014). There is a need for richer understanding among investing organizations regarding which 4IR technology tools should be combined and adapted or different parts of their value chain (Patsavellas; Kaur; Salonitis, 2021). To that end, digital inter-connectivity and data analytics capabilities can be used to provide real-time supply demand scenario planning and dynamic exception management (Malmstedt; Backstrand, 2022). Although there has recently been a lot of publicity surrounding the possibilities that digital transformation brings to SCs, adoption of advanced digital technology is still low, not considering the blurred lines and overlapping capabilities of many of th ese digital tools (Patsavellas; Kaur; Salonitis, 2021).

Intelligent Supply Chain, often interchangeably referred to as the smart, digital, or supply chain 4.0, is a concept that encompasses an end-to-end supply chain framework rather than focusing on specific tiers. This holistic approach treats the supply chain as a comprehensive system that combines technological and social elements with the goal of enhancing overall supply chain performance (Vlachos, 2021).

Cloud computing, big data, advanced data analytics, internet of things (IoT), artificial intelligence and machine learning technologies have impacted industry in recent years. Improving efficiency, promoting collaboration and digitization of supply chains to perform better, faster, and cheaper than traditional linear supply chains (Alias *et al*., 2014b; Vlachos, 2021). Another concept that industry is given increasing interest is called Digital Twins, that is a computer used models that represent actual physical objects and processes in real time (Patsavellas; Kaur; Salonitis, 2021). While companies are advised they need a ‘managerial revolution’ to take advantage of big-data as the key raw resource of the digital economy, the “people dimension” is one of the most overlooked areas in Industry 4.0 (Vlachos, 2021).

Table 2 provides all technologies discussed by the authors in the supply chain context and how many times they were mentioned.

Table 2 – Supply Chain Technologies

Data Analytics	IoT	Blockchain	CRM	GPS	RFID	Big Data	WMS	Scheduling Programmes	Machine Learning	Cloud Computing	TMS	QRcode	IoS	Artificial Intelligence	Bluetooth	GPRS	EDI	Data Service	ERP	Cameras	Author
	✓			✓	✓					✓										✓	Alias *et al* (2015)
																					Souza; Zhou (2015)
✓	✓		✓			✓	✓		✓					✓					✓		Ye; Zaraté; Kamissoko (2022)
	✓	✓			✓	✓				✓		✓						✓			Alacam; Sencer (2021)
	✓									✓			✓								Alias *et al.* (2014c)
							✓							✓						✓	Alias *et al.* (2014a)
✓			✓																✓		Yan *et al.* (2012)
																					Gerrits; Topan; Van Der Heijden (2022)
	✓	✓																			Wycislak (2023)
	✓			✓	✓		✓				✓						✓		✓		Le Roch *et al.* (2014)
						✓								✓							Verna; Koul; Singh (2020)
	✓			✓	✓										✓	✓					Shou-Wen; Ying; Yang Hua (2013)
✓	✓					✓			✓					✓					✓		Vlachos, (2021)
✓	✓	✓							✓					✓							Patsavellas; Kaur; Salonitis (2021).
✓																					Sharabati; Al-Atrash; Dalbah (2022)
✓	✓	✓		✓	✓	✓	✓		✓	✓				✓					✓		Liotine (2019)
																					Topan et al. (2020)
✓						✓			✓					✓							Malmstedt; Backstrand, (2022)
	✓			✓	✓			✓		✓	✓		✓							✓	Alias *et al.* (2014b)
6	**11**	**4**	**2**	**5**	**6**	**6**	**4**	**1**	**5**	**5**	**2**	**1**	**2**	**7**	**1**	**1**	**1**	**1**	**5**	**3**	**Total**

Source: Author (2023).

In total, twenty-one technologies were referred. According to Table 02, those that had mentioned above 5 times were GPS, Machine Learning, Cloud Computing, ERP, Data Analytics, RFID, Big Data, Artificial Intelligence and IoT.

Considered as supplier chain partner technology according to Lioninte (2019), ERP system plays as a transactional order data and information. For transactional data, each enterprise utilizes dedicated supply chain management software like SAP ERP to manage its operations (Ye; Zaraté; Kamissoko, 2022) These software systems store and document the information flow generated within each respective enterprise. Over time, businesses have employed different methods to handle their essential data, utilizing systems like CRM, ERP, or files such as Excel. This data is a valuable company asset, housing critical business information (Yan *et al*., 2012). The challenge arises from the absence of a data source design document and the utilization of file system databases, making it difficult to discern table structures, establish table relationships, and comprehend the embedded business rules within ERP systems, particularly when handling transactional data like stock movement and account payments (Yan *et al*., 2012). In addition to this integration software, there are also service packages that help in the online management of information in the supply chain known as SaaS - Infrastructure as a Service (Bowersox, 2011). Among the many tool options regarding logistics, the best known are WMS, for warehouse management, YMS for yard management and TMS for transportation chain management.

The utilization of real-time data from supply chain partners allows early identification of disruptions, allowing firms to proactively mitigate these issues before they impact the smooth flow of goods or services (Malmstedt; (Malmstedt; Backstrand, 2022). With the evolution of information technologies, the availability of increasingly voluminous data (Big Data) has been witnessed from diverse sources (Ye; Zaraté; Kamissoko, 2022). For Verna; Koul; Singh (2020) big data is a crucial aspect to enhance developing decision models that have the credibility to capture the strength of both analytics and intuitive qualitative approach. It also mentions that big data and artificial intelligence tools can be used in collaboration with multi-criterion decision-making methods to get desired results. With the help of Artificial Intelligence, organizations can proactively identify potential disruptions by developing algorithms that analyze demand data, financial information, and supplier performance data (Malmstedt; Backstrand, 2022). Additionally, machine learning (ML) and big data analytics have increasingly been used for supplier selection, sourcing risk management, production planning and control, inventory management, demand forecasting and demand sensing (Malmstedt; Backstrand, 2022). In addition to Big Data, another technology gaining ground in the market is called Blockchain. Blockchain can address a problem of trust that hinders information sharing. In the cloud-based model, the platform owner is the biggest beneficiary of trust amongst platform partners (Wycislak, 2023).

Monitoring supply chains involves many sensor technologies. This includes GPS sensors and RFID chips to track geographic positions (Alias *et al.*, 2015). GPS sensors provide the capability to calculate estimated arrival times of carriers and detect deviations in routing, route utilization, or departure times. In addition, thermal and climatic sensors are employed to monitor temperature and humidity conditions within shipping containers for example Alias *et al.* (2014a) Another aspect of interest is the monitoring of the weight of empty and loaded containers. It helps detect discrepancies between actual weights and expected values, potentially preventing overloading issues that could impact transportation vehicles and container handling equipment Alias *et al.* (2014a) The logistics sector is one of the domains that has already adopted some early IoT concepts around object identification and detection of conditions and statuses in real time (Alias *et al.*, 2014c). IoT technology encompasses information collection and transmission methods, such as RFID, barcode technology, GPS, video technology, temperature sensors, humidity sensors, chromatographs, GPRS, Bluetooth, Wi-Fi, and other transmission technologies (Shou-Wen; Ying; Yang Hua, 2013). The Internet of Things (IoT) represents the vision of a world of uniquely intelligent objects, carrying little processors and embedded computers (Alias *et al.*, 2014c). IoT is employed to enable real-time sensing and transmission of supply chain quality, acting as a centralized repository for all collected information. Additionally, it has the capacity to store feedback control information (Shou-Wen; Ying; Yang Hua, 2013).

Created to generate services to the IoT, the Internet of Services (IoS) is a technology that enables universal access to web-based services, allowing information processing across a lot of environments (Alias *et al.*, 2014c). The IoT and Cloud Computing are also two interconnected technologies that play a crucial role in the modern digital landscape. While IoT involves the network of physical objects (devices, vehicles, etc.) embedded with sensors, software, and connectivity, cloud computing, refers to a network of distributed and interconnected computers that collaborate in running applications simultaneously. This innovative technology offers remote users access to various IT infrastructure components, including network capacity, memory capacity, computing power, and software services, which can be seamlessly utilized over the internet. (Alias *et al.*, 2014c).

For adoption of any technology, organizations need to clearly understand the value proposition and innovation advantages as well as the deployment requirements for implementation, so they can as certain credible benefits that translate to compelling return on investment (Patsavellas; Kaur; Salonitis, 2021).

3.3. SUPPLY CHAIN CONTROL TOWER DEFINITION

The concept of a control tower in the supply chain originated from aviation, where it oversees the traffic of aircraft in both land and airspace (Vlachos, 2021). The first air traffic control tower was established at Croydon Airport in London, United Kingdom, in 1920. This tower was created to manage aircraft traffic and ensure the safety of aviation operations. From this milestone, the concept of a control tower expanded and was adopted at other airports worldwide, becoming an essential part of airport infrastructure. Since then, control towers have played a pivotal role in coordinating air traffic, providing guidance and instructions to pilots to en sure a safe and efficient flow of aircraft according to the History Croydon Airport website.

Control tower like concept was introduced by Jay Forrester in his work “industrial dynamics” more than 50 years ago, but only recently, it receives increasing interest across a broad spectrum of industries and considered as The Next Big Thing (Yan et al., 2012). It took a considerable amount of time since its inception for companies to develop logistics control towers with the aim of managing transportation routes (Vlachos, 2021). A typical control tower needs to exhibit two basic functions, monitoring, and control (Ye; Zaraté; Kamissoko, 2022). A Control Tower (CT) is a center of excellence that facilitates a coordinated network to continuously manage complexity and execute at levels that cannot otherwise be managed easily by humans Liotine (2019). For Verma *et al*. (2020), the CT merges data points from various streams and different levels to consolidate information for the high level of monitoring to pursue a goal to attain optimal process operations.

The new type of information and decision support systems that merge and visualize the supply chain information are called Supply Chain Control Towers (Topan *et al*, 2020). As the concept is relatively new the definition and capabilities are still evolving in time. Beyond the Supply Chain Control Tower, numerous derivations of control towers are discernible, encompassing Logistics Control Tower, Service Control Tower, Transport Control Tower, and Master Facilitative Control Tower, as shown in Table 3.

Table 3 - Control Tower Types

Control Tower Types		Author
Logistics Control Tower	A Logistics Control Tower is a centralized system that specializes in orchestrating and enhancing visibility within transportation operations, typically catering to companies engaged in Inbound and Outbound logistics.	Vlachos (2021); Alias *et al*. (2014).
Service Control Tower (SCT)	A Service Control Tower is a centralized hub for after-sales activities, leveraging real-time data, integrated data management, and transactional systems.	Topan *et al* (2020); Gerrits; Topan; Van Der Heijden (2022).
Transportation Control Tower (TCT)	Transportation Control Tower is a hub that streamlines and secures the entire transportation process through a transparent and automated system, fostering efficiency and accountability across the supply chain.	Alacam; Sencer (2021).
Master Facilitative Control Tower (MFCT)	A Master Facilitative Control Tower is a neutral platform that provides global information to independent control towers.	Souza; Zhou (2015).
Supply Chain Control Tower (SCCT)	A Supply Chain Control Tower is a system driven by data that captures and analyzes information from various supply chain processes.	Sharabati; Al-Atrash; Dalbah (2022).

Source: Author (2023).

Regarding control tower definitions, the most discussed concept is about the Supply Chain Control Tower. Because of that, this work presents each author's SCCT definitions. Around the 21st century, companies began to create SCCTs in response to the increased complexity resulting from the globalization of supply chains (Bhosle *et al*., 2011). Table 4 presents the definitions of each author about the Supply Chain Control Tower.

Table 4 - Supply Chain Control Tower Definition

Supply Chain Control Tower Definition	Author
It is a centralized command center that leverages real-time data, integrated data management, and transactional systems to harmonize processes and tools across the end-to-end supply service chain, thereby influencing business outcomes.	Gerrits; Topan; Van Der Heijden (2022).
It is a system characterized by its essential capabilities of visibility, analytics, and execution. It is designed to offer information supporting decisions at various levels, establishing different modes and frequencies of interaction between CT operators and clients.	Liotine (2019).
It is a digital information hub serving as 'digital twins' of dynamic product and information flow. Is a shared-service center that, like the digital twin of a traffic control tower, offers real-time monitoring of the status and performance of E2E activities.	Patsavellas; Kaur; Salonitis (2021).
Is a real-time transportation visibility platform.	Wycislak (2023).
It is a technology that enables End-to-End monitoring and transparency giving the ability to react and respond to a disruption enhanced with Supply chain risk.	Malmstedt; Backstrand (2022).
It is a central hub with the required technology, organization, and processes to capture and use supply chain data to provide enhanced visibility for short- and long-term decision making that is aligned with strategic objectives. Focus on real time data and integrated data management across the end to-end supply chain.	Vlachos (2021).
It is the ultimate tool for supply chain monitoring. As a decision-support system, while aiming at optimal process operation, the Control Towers, combine different data streams from all the dependent sublevels and display the consolidated details for the monitoring and controlling the processes at a higher level.	Verna; Koul; Singh (2020).
It serves as the information management and decision-making center of the supply chain	Ye; Zaraté; Kamissoko (2022).
It is a flexible and agile control structure for coordinating and managing the flow of goods and information throughout the entire supply chain.	Souza; Zhou (2015).
It is a system designed for real-time visibility across the entire supply chain, empowering operators to make informed decisions promptly and take swift actions when necessary.	Yan et al. (2012).

Source: Author (2023).

Although the concept of the SCCT is new, it seems that there is a consensus among practitioners, researchers and scholars about its definition and components (Sharabati; Al-Atrash; Dalbah, 2022). Similar to an airport control tower, the SCCT, works as the most central part of supply chain information. Controls the sub databases and records the latest data updated from supply chain software in real time. These data include KPIs, key business, logistics and distribution centers (Ye; Zaraté; Kamissoko, 2022).

Serving as a centralized hub, the SCCT collects, analyzes, and visualizes supply chain progress, issuing alerts and triggering corrective actions in response to deviations from the organizational strategy, ultimately enhancing performance (Sharabati; Al-Atrash; Dalbah, 2022). Companies aim to use SCCTs to monitor their supply chain and to generate alerts (Topan *et al.*, 2020). Equipped with Supply chain control tower, more precise mitigations activities can be executed given the detail supply chain mapping and historical data of similar events and actions (Malmstedt *et al.*, 2020). It must provide fundamental capabilities to enable the levels of visibility and awareness to achieve the company's goal Liotine (2019). Its needs to be fulfilled by the system capable of real-time tracking, alerts, visualization, and giving quick solutions is achievable (Verma; Koul; Singh, 2020).

The SCCT offers an intelligent way for concurrent SC planning and execution. Real-time information collection and advanced analytics are combined with on -the-spot decision making by experts to reconfigure the SC based on simulating alternative plans before executing them (Vlachos, 2019).

3.4. SUPPLY CHAIN CONTROL TOWER FUNCTIONALITIES

Supply chain control is extensively researched in the literature. However, there are limited empirical studies on the development and implementation of supply chain control towers, mainly due to the dominance of 3PL/4PL service providers in operating these towers (Vlachos, 2021).

Wislack (2020) mentions that Supply Chain visibility is difficult to achieve in practice, making a key concern for organizations. Liotine (2019) defends that the most significant challenges in the visibility of a Control Tower include:

- Technological Limitations: platforms may have different serialization formats, affecting data flow. Blockchain technology, though promising, requires extensive system interconnectivity.
- Lack of Regulation: Absence of regulatory oversight can lead to conflicts of interest and distortions when shared with costumers.

- Demand Forecast Accuracy: this is essential to reduce inventory costs. Shifting to near-real-time demand sensing is crucial. CTs should not only provide visibility and alerts but also empower operators to make decisions in response to operational issues and disruptions.

Table 5 presents the SCCT functionalities. Technology Integration applies to all technologies mentioned in Table 7 and papers that mention about Data Integrated Management by (Gerrits; Topan; Van Der Heidjen, 2022; Topan *et al*., 2020).

Table 5 - SCCT Functionalities

Decision Making	Tracking	Monitoring	Real time	Notification/Alerts	Forecasting	Visibility	Cost Control	Integrated Technology	Inventory Level	Key performance Indicator	Collaboration	Risk Management	**Author**
		✓	✓			✓	✓	✓			✓	✓	Alias *et al.* (2015)
	✓	✓				✓	✓		✓		✓	✓	Souza; Zhou (2015)

✓		✓	✓				✓	✓		✓		✓	Ye; Zaraté; Kamissoko (2022)
								✓			✓		Alacam; Sencer (2021)
		✓				✓	✓	✓			✓		Alias *et al.* (2014c)
		✓				✓		✓		✓			Alias *et al.* (2014a)
✓	✓			✓	✓	✓	✓	✓	✓	✓			Yan *et al*. (2012)
		✓		✓			✓		✓				Gerrits; Topan; Van Der Heijden (2022)
	✓					✓	✓	✓			✓		Wycislak (2023)
	✓							✓	✓				Le Roch *et al.* (2014)
	✓	✓		✓		✓		✓			✓		Verna; Koul; Singh (2020)
	✓		✓			✓		✓	✓			✓	Shou-Wen; Ying; Yang Hua (2013)
✓					✓	✓	✓	✓	✓	✓		✓	Vlachos (2021)
✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	Patsavellas; Kaur; Salonitis (2021)
✓	✓			✓		✓	✓	✓	✓		✓	✓	Sharabati; Al-Atrash; Dalbah (2022)
✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Liotine (2019)
		✓	✓	✓				✓	✓	✓		✓	Topan *et al*. (2020)
✓		✓	✓	✓	✓	✓	✓	✓	✓			✓	Malmstedt; Backstrand (2022).
	✓	✓	✓	✓	✓	✓	✓	✓			✓		Alias *et al.* (2014b)
7	**10**	**12**	**8**	**9**	**6**	**10**	**13**	**18**	**11**	**6**	**10**	**10**	**Total**

Source: Author (2023).

The functionalities included in Table 5 are those which appeared in more than 5 articles.

The Control Tower in supply chain management acts as a pivotal platform, overseeing processes and offering decision support through real-time data visualization and optimization methods (Verna; Koul; Singh, 2020). It is instrumental in supporting decisions across various levels and frequencies, emphasizing collaboration with clients for effective decision-making Liotine (2019). SCCT, utilizing intelligence technologies, enhances decision-making by minimizing costs and improving overall efficiency (Sharabati; Al-Atrash; Dalbah, 2022).

Decision-making within SCCT involves strategic, tactical, and operational planning activities, addressing short-term impacts and relying on real-time data (Gerrits; Topan; Van Der Heijden, 2022). The model's adaptability and inclusivity, advocated by Alias *et al*. (2015), are crucial for effective alignment and decision-making in complex supply chain operations. Control Towers, overseeing modules like warehouses and transportation systems, offer resource efficiency and resilience benefits (Alias *et al*., 2015). Real-time data collection and analysis enable swift presentation of action alternatives, resulting in accelerated processes, cost savings, and risk reduction (Gerrits, Topan, Van der Heijden, 2022).

Souza and Zhou's platform aids in visualizing supply chain networks, identifying disruptions, and supporting risk mitigation through scenario analysis (Souza; Zhou, 2015). SCCTs, categorized by Shou-Wen and Yang Hua (2013), enhance visibility across strategic, tactical, and operational levels, ensuring adaptability to market changes. Yan et al. (2012) stress the significance of supply chain visibility, encompassing inventory, demand, and logistics.

Real-time data collection in SCCT involves continuous monitoring, data sensors, and advanced technologies like machine learning for predictive analysis (Yan et al., 2012; Ye, Zaraté, and Kamissoko, 2022). Wycislak (2023) emphasizes how enhanced real-time visibility optimizes truck space utilization, reducing the carbon footprint. Challenges in real-time visibility include factors spanning individual, organizational, technological, and environmental aspects (Wycislak, 2023).

Collaboration and compliance among supply chain partners are essential for data accuracy, repeatability, and overall supply chain ecosystem benefit (Wycislak, 2023). Liotine (2019) suggests interconnections between Control Towers to enhance transportation information sharing. Le Roch *et al.* (2014) highlight the unifying role of the EPCglobal® standard in event tracking. Yan et al. (2012) stress the importance of data comprehension and efficient utilization for substantial business benefits.

Integration of multiple control towers, strategic partnerships, and addressing challenges like a lack of collaboration, accuracy issues, and budget constraints are crucial (Alias et al., 2015; Patsavellas, Kaur, Salonitis, 2021). Sharabati, Al-Atrash, Dalbah (2022) emphasize SCCT's role in unifying supply chain components and enhancing collaboration for strategic goals.

The operational planning decisions within SCCT, as detailed by Topan et al. (2020), involve KPIs, interventions, alerts, and information content. Yan et al. (2012) present a tailored SCCT model for cost reduction, focusing on KPIs like customer demand, net inventory levels, and order status tracking. Planners respond to alerts by reviewing and prioritizing interventions, automating standard interventions while facing challenges in setting appropriate thresholds (Gerrits, Topan, Van der Heijden, 2022).

CT activities enhance supply chain operations, leading to cost reduction, improved customer service, and long-term profitability (Sharabati, Al-Atrash, Dalbah, 2022; Yan, Tan, Koh, Tan, Zhang). The effectiveness of SCCT relies on promptly displaying KPIs, supporting operational planning decisions with real-time data, and facilitating proactive decision-making (Topan et al., 2020). When effectively applied, SCCT functionalities optimize supply chain efficiency, enhance responsiveness, and provide competitive advantages for organizations.

3.5. AREAS INVOLVED IN THE SUPPLY CHAIN CONTROL TOWER

According to Liotine (2019) SCCT must include supplier partnerships, new technology, collaboration, strategic alliances, artificial intelligence, and lean manufacturing (Sharabati; Al-Atrash; Dalbah, 2022; Wycislak, 2022).

SCCT contents are inbound and outbound logistics, procurement, manufacturing, warehousing, order processing, customer service, transportation and demand planning (Sharabati; Al-Atrash; Dalbah, 2022). Yan et al. (2012) emphasizes it must include customer demand management, inventory planning, order tracking, event notification or alerts, report and order consolidation. Table 6 shows enterprise areas that should be included in the SCCT. These areas are defined according to Sharabati; Al-Atrash; Dalbah, 2022.

Table 6 - Areas Involved in the Supply Chain Control Tower

Planning	**Procurement**	**Inbound**	**Order Processing**	**Manufactuing / Production**	**Transportation**	**Warehousing**	**Outbound**	**Costumer Service**	**E2E**	**Author**
	✓									Alias *et al.* (2015)
✓		✓	✓	✓		✓	✓			Souza; Zhou (2015)
					✓					Ye; Zaraté; Kamissoko (2022)
										Alacam; Sencer (2021)

										Alias *et al.* (2014c)
										Alias *et al.* (2014a)
✓			✓							Yan *et al*. (2012)
									✓	Gerrits; Topan; Van Der Heijden (2022)
			✓							Wycislak, 2023
✓										Le Roch *et al*. (2014)
										Verna; Koul; Singh (2020)
	✓			✓	✓	✓				Shou-Wen; Ying; Yang Hua (2013)
									✓	Vlachos (2021)
✓				✓					✓	Patsavellas; Kaur; Salonitis (2021)
✓	✓	✓	✓	✓	✓	✓	✓	✓		Sharabati; Al-Atrash; Dalbah (2022)
✓					✓					Liotine (2019)
									✓	Topan *et al*. (2020)
									✓	Malmstedt; Backstrand (2022)
				✓	✓					Alias *et al.* (2014b)
5	**3**	**2**	**4**	**5**	**5**	**3**	**2**	**1**	**5**	**Total**

Source: Author (2023).

In Table 6 Procurement area also represents Supplying area proposed by Shou-Wen, Ying, Yang Hua (2013). Planning includes demand planning, forecasting and inventory planning mentioned by Le Roch *et al*.(2014), Topan et al (2020), Malmsted; Backtrand (2022), Vlachos (2021), Lionete (2019), Patsavellas; Kaur; Salontis (2021), Sharabati; Al-Atrash; Dalbah (2020) . Order Processing includes Order Management (Wycislak, 2023) and Order Fulfillment (Souza; Zhou, 2015, Lionete 2019).

One of the major contributing factors for the lack of SC visibility is the challenge of identifying the specific areas of priority for further capability development. Visibility can positively affect manufacturing, transaction activities, planning, supplying, and evaluation on both operational and strategic choice levels. On an operational level, it can impact forecasting, planning, and scheduling efficiency, along with execution accuracy and speed (Patsavellas; Kaur; Salonitis, 2021). The major aspects of the supply chain business include procurement, transportations, warehousing, manufacturing, distribution, and information servicesShou-Wen; Ying; Yang Hua (2013). Some authors do not explain exactly the areas that should be included in

SCCT, but they mention that SCCT allows end-to-end (E2E) monitoring as shown in Table 3.

End-to-end supply chain encompasses all business supply chain operation including suppliers, planning, manufacturers, transportation carriers, and third-party logistic vendors to track the active movements of goods from origin to destination Liotine (2019) End-to-end supply chain visibility is a need that SCCTs can practically fulfil, acting as an inter-organizational coordinating platform (Patsavellas; Kaur; Salonitis, 2021). Because of these factors, it becomes crucial to have a way to intelligently visualize the entire supply chain from end to end to assist in making more strategic business decisions.

End-to-end SC visibility is needed to have real-time monitor and control for risks (Sharabati; Al-Atrash; Dalbah, 2022).Visibility is essential for SC agility and responsiveness, and it reduces inventory and cost (Patsavellas; Kaur; Salonitis, 2021; Sharabati; Al-Atrash; Dalbah, 2022). Visibility requires coordination and information sharing among all SC partners, which are crucial for decision-making but difficult to achieve in practice (Wycislak, 2023).

Malmsted; Backstrand (2022) shows an example by Procter & Gamble that have developed a control tower system for End-to-end supply chain monitoring. It integrates real-time data, from inventory levels to road delays and weather forecasts, for its own plants as well as suppliers and distributors. When a problem occurs, the system can run scenarios to identify the most effective solution on how to mitigate the problem. Despite these definitions, SCCT is gaining more space due to the digital technology development related to the Internet and logistics to solve the problem of the information availability between partners (Sharabati; Al-Atrash; Dalbah, 2022). The SCCT can constitute a 4IR digital information hub serving as the single access point for all decision makers, planners, buying teams and cross-organizational SC partners. SCCT hubs aggregate, correlate and distribute information for early detection of risk and opportunities, providing monitoring, measurement and management (Patsavellas 2020).

3.6. TECHNOLOGIES APPLIED IN SUPPLY CHAIN CONTROL TOWER

Although new, the Control Tower comprises integrated supply chain and a platform to decision-making (Alias *et al.*, 2015). Fulfilled by a system capable of real-time tracking, alerts, visualization, and giving quick solutions. It merges data points from various streams and different levels Verna; Koul; Singh (2020). It is designed to consolidate data for thorough monitoring with the objective of optimizing operational efficiency. The success of a control tower is based on four pillars: people, processes, technology, and information flow (Yan *et al*., 2012). The implementation of SCCT solution requires a collection of technologies, such as data connectivity, data integration, data standardization and automation (Yan *et al*., 2012).

Liotine (2019) and Vlachos (2021) provide valuable insights into the technology landscape of Supply Chain Control Towers (SCCTs), encompassing Enterprise Resource Planning (ERP), Warehouse Management Systems (WMS), and Transportation Management Systems (TMS). Liotine (2019) underscores the pivotal role of these supply chain partner technologies, along with cloud-based technologies and analytic technologies, in enhancing visibility and decision-making within the supply chain. On a complementary note, Vlachos (2021) expands on this technological framework by categorizing SCCT technologies into long-linked technologies, mediating technologies, and intensive technologies. The integration of long-linked technologies, such as the Internet of Things (IoT) and big data, aligns with Liotine (2019), who emphasizes on comprehensive data collection. Moreover, Vlachos (2021) introduces mediating technologies like Electronic Data Interchange (EDI), cloud platforms, and apps, which resonate with Liotine's discussion of cloud-based technologies facilitating interconnectivity. Intensive technologies brings the concept of machine learning models for risk management and SC planning and execution. Together, these perspectives offer a comprehensive understanding of the crucial technological facets for an effective operation of SCCTs in contemporary supply chain management.

Table 7 shows all technologies that should be included in the SCCT. These technologies are defined according to Liotine (2019), Vlachos (2021), Ye; Zaraté; Kamissoko, (2022) and Le Roch et al. (2014).

Table 7 - SCCT Technologies

Data Analytics	**IoT**	**Big Data**	**WMS**	**Machine Learning**	**Cloud Computing**	**TMS**	**Artificial Intelligence**	**ERP**	**Author**
	✓				✓				Alias *et al.* (2015)
									Souza; Zhou (2015)
✓	✓	✓	✓	✓			✓	✓	Ye; Zaraté; Kamissoko (2022)
	✓	✓			✓				Alacam; Sencer (2021)
	✓				✓				Alias *et al.* (2014c)
			✓				✓		Alias *et al.* (2014a)
✓								✓	Yan *et al*. (2012)
									Gerrits; Topan; Van Der Heijden (2022)

	✓								Wycislak (2023)
	✓		✓			✓		✓	Le Roch *et al.* (2014)
		✓					✓		Verna; Koul; Singh (2020)
	✓								Shou-Wen; Ying; Yang Hua (2013)
✓	✓	✓		✓	✓		✓	✓	Vlachos (2021)
✓	✓			✓			✓		Patsavellas; Kaur; Salonitis (2021)
✓									Sharabati; Al-Atrash; Dalbah (2022)
✓	✓	✓	✓	✓	✓	✓	✓	✓	Liotine (2019)
									Topan et al. (2020)
✓		✓		✓			✓		Malmstedt; Backstrand (2022)
	✓				✓	✓			Alias *et al.* (2014b)
6	**11**	**6**	**4**	**5**	**5**	**2**	**7**	**5**	**Total**

Source: Author (2023).

Wycislak, (2023) mentions companies that shifted their transportation model to focus on Control Towers, such as Unilever, Procter and Gamble, and Carlsberg. Unilever, for instance, established separate Control Towers for different regions, including Europe, Asia, North and South America. By centralizing procurement and partnering with low-cost carriers and freight forwarders, they achieved substantial cost saving. The key to setting up Control Towers was the implementation of Transport Management Systems, which facilitated the centralization of various operations. These Control Towers also played a crucial role in the adoption of large-scale digital platforms and a new resource-sharing model, enhancing real-time visibility across the supply chain (Wycislak, 2023).

To maintain a supply chain control tower, it is essential to use technologies that allow data analysis from all areas comprised in the SC. The SCCT relies on big data analytics to drive the acquisition, cleaning, and harmonization of data from multiple sources across the entire demand network in real time through cloud technology Liotine (2019) SCCT capabilities emerge from sociotechnical interactions. Intelligent SC planning and execution should emerge by interactions between technologies like big data and advanced analytics with people skills and abilities (Vlachos, 2021). Malmstedt, Backstrand (2022) also points that supply chain resilience can be improved with the help of data analytics and big data.

Data sensors distributed in the information flow of the supply chain transmit real-time data to the dashboard of the control tower, and the data analysis center of the control tower will use new technologies such as machine learning to predict time series data to warn (Ye; Zaraté; Kamissoko, 2022). Vision-based detection sensors and systems are used to visually detect anomalies and deviations. They utilize video streams from network/IP cameras along with image processing and computer vision algorithms (Alias *et al.* 2014a).

Monitoring supply chains involves many sensor technologies. This includes GPS sensors and RFID chips to track geographic positions (Alias *et al.*, 2015). In the control tower, the primary tool for collecting information is the RFID system (Shou-Wen; Ying; Yang Hua, 2013). Many organizations have experimented RFID technology to assess its productivity potential. According to (Le Roch *et al.* (2014).RFID enables bulk reading of item identifiers via radio frequency, facilitating the tracking of item flows at sites equipped with RFID readers. After capturing an identifier, it must be further enriched, published, and shared to be valuable to all parties involved. The EPCglobal® standard supports this process, especially in intercompany logistics information systems. Leveraging this standard, partners gain the ability to create and execute highly interoperable solutions that are less dependent on the information system already in place in the chain: ERP, WMS, TMS, EDI. This standard holds the potential to be a well-suited framework for RFID tracking in open and collaborative environments (Le Roch *et al.* (2014).

4. CONTENT ANALYSIS OF INTERVIEWS WITH COMPANIES

With the aim of understanding what the market considers a Supply Chain Control Tower, three companies were interviewed. For sake of confidentiality, the company names were abbreviated as A, B and C. Company A is present in the mining sector in eighteen countries and has more than one thousand employees. In Brazil, it operates in six states and has around seventeen thousand employees. Company B operates in the refrigeration and engine markets. Present in nine countries with more than fifteen thousand employees with four plants in Brazil. Company C operates in the civil construction sector and has operations in twenty-three countries, eleven in Brazil and thirteen abroad with more than five thousand employees.

Although they are considered large companies for being multinationals and have an end-to-end chain, the only 3PL company is A. All storage, order preparation or merchandise transportation services are carried out by a third-party company.

Each company holds its unique vision of SCCT. Company A has a tower dedicated to overseeing logistics operations, with a primary focus on inbound and outbound areas. Company B aspires to develop a tower capable of digitizing not only the supply chain but also all facets of the company. On the other hand, Company C currently employs the tower for monitoring indicators across all areas of the company.

Table 8 represents the reason why companies decided to implement the tower. Basically, Company A is driven by operational issues while B and C were having issues with historical data.

Table 8 - Company motivation to implement the Tower

What is the main motivation to implement SCCT?		
A	**B**	**C**
Driven by a range of issues related to the loading and unloading of goods.	Need to deepen data analysis due to the often superficial and frequently lacking historical context of the data used.	High cost of external consulting; Lack of standardization in indicators; The need to eliminate human errors; routine automation; data discrepancies; the pursuit of easy information access; the necessity to maintain a historical record of indicators, and the optimization of space and costs.

Source: Author (2023).

To implement the Control Tower, companies identified key assumptions shown in Table 9. Company A emphasizes the need for real-time functionality to control the entire operation and take necessary actions regarding its logistics service providers. Company B insisted that it must be a cloud-based tool, while Company C required a tool where all company indicators could be consolidated.

Table 9 - Principles to Implement the Tower

What were the main functionalities considered in the SCCT project?		
A	**B**	**C**
Enhancement of operations through real-time visualization, implementation of a cargo scheduling system, and establishment of Control Centers (CCOs) for both inbound and outbound operations.	Be a cloud-based tool to facilitate access and the ability to store vast databases.	Concentrate all indicators of the company in one place.

Source: Author (2023).

Table 10 outlines the procedural steps undertaken by companies in implementing the Control Tower. Company A executed a systematic implementation process, fostering adaptability to changes and continuous refinement of its methodology over a seven-year period. In 2020, Company B initiated the process by mapping and integrating data from ERP systems. Subsequently, they engaged with strategic areas to develop a tool for their key performance indicators. Company C, in the initial phase, delineated the specific areas to be incorporated into the Control Tower. With the collaboration of the Business Intelligence (BI) team, a distinct category was established for each area within the control tower, facilitating the visualization of performance indicators. For any modification in the Control Tower it is required the validation by the BI team. Notably, all Towers are still continually improving. However, company B is the only one that still has few areas implemented in the tower and it will take longer to integrate new technologies into it.

Table 10 - SCCT Implementation Process

How was the SCCT implementation process executed?		
A	**B**	**C**
Initially, the company directed its efforts towards structuring the cargo scheduling system. Subsequently, it developed	The implementation was carried out by the IT team, first mapping data extracted from Oracle and SAP with the aim of unifying.	Decision on which areas would be included in the Tower. Discussions with the respective areas to understand the

Control Centers, first for inbound operations and later for outbound operations.	Secondly, they contacted strategic areas with a large volume of data to test the tower. Each area has it own's database and can create your own dashboard.	perspectives they would like to have in the Tower. The Business Intelligence (BI) team supports the needs of the Tower. Validation is performed with each change made to ensure accuracy and effectiveness.

Source: Author (2023).

Company A additionally underscores real-time visualization, providing insights into ship arrivals, cargo unloading progress, and the current location of goods on highways. In parallel, Company B emphasizes the seamless integration of cloud-based data and the automated intelligence that eliminates duplicate data without requiring human intervention. Company C focuses on resource optimization and user-friendly accessibility. Both Company A and C highlight the control tower's capacity to streamline decision-making, whether at strategic levels or in day-to-day operational scenarios. Table 11 delineates the key advantages of the control tower.

Table 11 - Key Advantages of the Tower

What are the key advantages or positive outcomes of its usage?		
A	**B**	**C**
Real-time visualization of the arrival of ships and goods at the company's facilities; the ability to make daily decisions based on current information; monitoring the responsibilities of each service provider and reducing the response time for operational issues.	Ability to visualize extensive databases; intelligent data handling (including connection and elimination of duplicates), and the autonomy granted to various areas to build their own visualizations.	Provide visibility for all indicators with easy access. Strategic decisions support and organizational resources efficient optimization.

Source: Author (2023).

The components comprising the control tower for each company are outlined in Table 12. Company A exclusively monitors Inbound and Outbound operations, covering all incoming raw materials and finished products leaving the facility. Company B encompasses additional areas, including Sales and Operations Planning (S&OP), Sales and Operations Execution (S&OE), and Materials Planning. Global Logistics and Importation are still in development, and other areas are under consideration for incorporation into the Tower, such as Logistic Operations and Exportation. Company C, among the three, has the most extensive array of areas integrated into the tower, spanning manufacturing, services, and expenses. The distinction lies in the inclusion not only of areas within the supply chain but also external ones, such as Security and Maintenance. Also, company C considers Logistics as the Inbound and Outbound areas.

Table 12 - Areas that comprise the Control Tower

Which specific operational areas or domains are monitored within the tower?		
A	**B**	**C**
Inbound and Outbound.	HR, Sales, IT, S&OP, Materials Planning, S&OE, Global Logistics (ongoing)., Importation (ongoing).	Manufacturing, Operational Results, Safety, Logistics, Maintenance and Utilities, S&OP, Services, and Expenses.

Source: Author (2023).

Performance indicators for each business vary according to their operational domains, as illustrated in Table 13. For Company A, in the outbound perspective, some of the evaluated indicators include loading and unloading times, operation and deadhead freight time. On the inbound side, data includes ship unloading metrics categorized by customer, time, day, hold, and others. Inventory-related indicators are monitored by the Warehouse, another functional area within the company. Additionally, Company A operates in three different locations in Brazil, potentially leading to variations in the mentioned indicators. For Company B, within the materials planning area, evaluated indicators include inventory in transit, on hand, work in progress (produced and purchased) categorized by material portfolio, planner, with visualizations available on a daily, monthly, or annual basis. Meanwhile, indicators assessed by Company C vary based on specific functional areas. For the transportation and logistics domain, some of the indicators include volume per shipment and per Distribution Center. The key performance indicator for this area is On Time On Full (OTIF), which means the delivery of the right product in the right quantity ordered by the customer at the agreed-upon location.

Table 13 - Key Performance Indicators

Which Key Performance Indicators (KPIs) are under continuous monitoring within the tower?		
A	**B**	**C**
Unloading and loading times, number of scheduled and loaded vehicles, no show, dead freight, productive impact rate, conference waiting time, pawning time, ship cargo data such as quantities and tons, discharges from the ship's hold among others.	In the Materials Planning area, for example, indicators include inventory levels in transit, on hand, work-in-progress purchased and produced for all plants in Brazil, categorized by planner and origin.	For logistics: costs and revenue, OTIF, volume/freight, CD/volume and WMAPE.

Source: Author (2023).

Verna; Koul; Singh (2020) highlight that the SCCT serves as a platform for robust decision-making, providing information to support decisions at all levels (Alias *et al.*, 2015). Companies A, B, and C all underscore the control tower as a pivotal tool facilitating decision-making processes. In the case of company, A, monitoring is carried out by technicians working in alternating shifts. Decisions are informed by indicators, cameras, and their operational expertise. For Company B, particularly in Materials Planning, the dashboard undergoes daily evaluation in a routine meeting, with decisions typically made by the area manager. The dashboard is also presented in internal management forums to highlight inventory progress. Similar to Company B, Company C adopts a decentralized monitoring approach, where each area manages its own operations. There is no centralized forum for data presentation; thus, the area relies on the dashboard to assess performance, typically on a weekly or monthly basis due to update limitations.

Table 14 - Decision Making Authority.

How is the tower tracked, and who holds decision-making authority?		
A	**B**	**C**
The monitoring is conducted by technicians, one during the day shift and another during the night shift. They are responsible for making decisions based on the indicators, monitoring cameras, and their operational experience.	Data governance is IT responsibility, but each area has a manager and an analyst responsible for processing the database's data. In terms of monitoring, it is at the discretion of each area. In the Material Planning area, monitoring of the KPIs present on the dashboard is carried out by the entire team all day and decision-making is carried out by the manager.	Monitoring and decision-making are decentralized, each area conducts its own tracking of the Tower and make decisions according to its specific needs.

Source: Author (2023).

While Inbound data is available 24 hours a day, Outbound receives less frequent updates, resulting in reactive decision-making for business A. The tool lacks an alert system to notify when attention is required. Decisions about carrier prioritization are made by the technician, and customers are unable to track the location of their merchandise. For Company B, data updates occur according to each specific area. In Materials Planning, three updates are performed throughout the day, while in Company C, only one daily update takes place. C encounter challenges in table connections, necessitating some manual inputs. To access the Control Tower, the requester undergoes a profile analysis, and the platform is inaccessible on weekends. These limitations stem not from the tool itself but rather the type of package contracted by the company. All three companies benefit from support by a dedicated data team that assists in implementing new ideas in the Control Tower. This arrangement can be considered advantageous due to the specialized support, but it may also pose a disadvantage as it introduces potential delays in certain matters. Table 15 shows the limitations according to A, B and C.

Table 15 - Limitations of the Control Tower

Are there any limitations or constraints associated with the control tower utilization? For instance, updates, gaps, or manual inputs?		
A	**B**	**C**
Outbound platform receives less updates during the day and can only make decisions reactively; The tool does not generate alerts; The technician who decides which carrier will load first.	There is no real-time update. Updates are made according to the application, that is, each area decides how often it will be updated. Dependency on IT team and external consultants	The update is made once a day; There are some gaps in the compressed tables; Not everyone has access (profile analysis - request level) and is not possible to access on weekends; Dependence on the BI team for new implementations in the tower and allows manual data entry.

Source: Author (2023).

Table 16 outlines the technologies employed in the functionality of the control tower. All of them share a common reliance on an ERP system as an essential database. Company A utilizes the SAP system, while both B and C leverage both SAP and Oracle. Data input into the Control Tower necessitates an Application Programming Interface (API) due to the intricacies of data extraction from the ERP. For Inbound processes, Company A employs SAP ATM. This tool facilitates real-time visualization of ship unloading, incorporating a beeping process to automatically signal on the platform as goods are removed from the hold. Monitoring is further facilitated through cameras within the company's premises using the Digifort tool. Digifort includes an identification system capturing the moment a truck arrives at the company and recording the time taken by the operator to handle the merchandise. Logpyx, another utilized tool, extracts information from Digifort, enabling the monitoring of performance indicators.

In the Outbound process, SAP HANA manages the monitoring of load scheduling, allowing technicians real-time observation of windows, vehicle arrivals, loading status, and other relevant data. Visualization of indicators is handled by a separate system called GPAO. The company's extensive geographic coverage is facilitated by four satellites across Brazil, GPS implementation in its truck fleet, and trackers on carriers' trucks, providing technicians with a map-based visualization of merchandise entry points. Company B utilizes the API to transmit data to Google Cloud, where each plant and area decides on the visualization tool, such as Qlik Sense or Power Bi. Similarly, Company C employs a comparable mechanism but with unspecified Cloud tools.

Table 16 - Technologies implemented in the SCCT

Which systems and technologies are utilized in the Control Tower?		
A	**B**	**C**
Some of the key systems include SAP ATM for Outbound, Digifort for camera monitoring, the Logpyx tool and trackers on trucks. Monitoring loading windows and visualizing the truck fleet are facilitated using SAP and geographic location. WMS is also used, although controlled separately.	ERP systems such as SAP and Oracle; Google Cloud for the Data Lakehouse; analytical tools like Click Sense, with the prospect of incorporating Power BI in the future	ERP systems such as SAP and Oracle. Power BI tool.

Source: Author (2023).

All the studied companies have not yet completed the implementation of the Control Tower. Table 17 presents the main opportunities that the companies visualize and their next main steps.

Table 17 - Potential Opportunities for the Tower.

Which future potential opportunities does the company envisage with the SCCT ?		
A	**B**	**C**
Generate alerts for potential issues through the implementation of intelligence. Adopt SAP ATP for standardization and improved decision-making; Allowing customers to track the real-time location of their goods; Implement trackers on internal trucks; Expand to the implementation of SAP Standard and Machine Learning.	Expansion to more areas; Integration with Artificial Intelligence for enhanced insights; Additional data mapping for the use of robust tools such as Power BI in BR plant.	Communication improvements between areas; Specific tracking within each sector and the creation of a global forum for discussions and collaboration.

Source: Author (2023).

Company A mentions that some of its upcoming initiatives include the implementation of intelligent features such as machine learning. This will enable the identification of bottlenecks and through alerts/messages in the Control Tower. They are also considering factors such as inventory levels, capacity, and demand to enhance connectivity with other logistics areas. In addition to the observed benefits, Company B has identified promising opportunities for the ongoing evolution of the Data Tower. These include expansion to more areas, integration with Artificial Intelligence for enhanced insights, the creation of an API for Oracle and SAP integration, and additional data mapping for the use of robust tools such as Power BI. While Company C does not explicitly outline its next steps, it emphasizes the need to improve communication between areas of the tower, as some use the same database but in different visualization formats. They also underscore the importance of the tower as a tool for more strategic managerial decision-making.

Despite the theme being Supply Chain Control Tower none of the interviewed companies fit this classification. Company A could be considered as a Logistics Control Tower due to its management focus on Inbound and Outbound areas. Companies B and C are on the rise of developing their towers and might classify as such in the future if they choose to invest in intelligent technologies. Both are large companies with integrated logistics chains. Even though Company B is still in development, it shows itself to align with a data lake or data tower.

The substantial contribution of these companies significantly enriched the study, enhancing it with valuable insights and essential data for the research. The incorporation of this information is crucial to provide a profound understanding of the context and the significance of the study at hand.

5. GAPS BETWEEN LITERATURE AND PRACTICAL APPLICATIONS IN COMPANIES

As mentioned by Yan *et al*. (2012), there is a growing interest in industries regarding the implementation of control towers. However, such implementation is not straightforward, requiring several steps to achieve a resilient tower (Vlachos, 2021). Despite being discussed in the literature, few articles detail the implementation of an SCCT, which can lead to different interpretations of what truly constitutes an SCCT. Considering the information provided by interviewed companies about their implementations and what the literature presents, the key stages of the SCCT are highlighted in table 18:

Table 18 - SCCT Key Stages

SCCT key stages	
Step 1	Map the company's needs; Define what type of tower the company needs; Understand the need for consultancy; Obtain data from third parties; Establish connection with the necessary areas.
Step 2	Definition: - Technologies; - Involved Areas; - Accesses; - Functionalities; - KPIs.
Step 3	Databases; Dashboards; Tests.
Step 4	Tower monitoring.

Source: Author (2023).

Step 1 is a pre-project. It is essential to map the current situation of the company and identify the main gaps to be filled. Understanding the ideal type of tower for the company, possibly with the assistance of external consultancies. In this phase, obtaining data from carriers and 3PLs, including georeferenced data and information about cargo, travel, and workers, is of great importance. Additionally, establishing effective connection between the company's IT or Business Intelligence team and the areas covered by the tower is fundamental.

In Step 2: Tower requirements, it is necessary to address issues such as the necessary technologies, the desired type of visualization, the responsible parties for each area, accesses, involved areas, decision-making, and tower functionalities. Defining which indicators will be evaluated is a crucial step. In Step 3: Implementation, the process involves connecting databases through the cloud, creating visualization dashboards, and conducting tests until achieving 100% functionality. In Step 4: Monitoring/Improvements, it is essential to monitor the tower by an IT team, providing support for any problems. Additionally, working on improvements, such as integrating new machine learning or artificial intelligence technologies.

In the context of definitions, the literature presents different types of control towers. Vlachos (2021) and Alias *et al*. (2014a) state that a Logistics Control Tower is a centralized system specialized in orchestrating and enhancing visibility in transportation operations, typically serving companies involved in inbound and outbound logistics. This aligns precisely with the tower implemented in company A. To keep the tower in operation, using ERP tools, smart cameras for monitoring and information capture, geographic location, WMS, tracking tools, and dashboards is considered essential.

Sharabati, Al-Atrash and Dalbah (2022) argues that a Supply Chain Control Tower is a data-driven system, capturing and analyzing information from various supply chain processes, which fits the proposals of B and C. Yan *et al*. (2012), on the other hand, mention that it is a system designed for real-time visibility throughout the supply chain, empowering operators to make informed decisions promptly and act quickly when necessary. While B and C are aligned in terms of visibility, improvements in the control tower are necessary to achieve real-time visibility.

The literature also highlights that the tower performs end-to-end monitoring, as presented by Malmstedt, Backstrand (2022). However, this is not the reality for companies, given the need for significant investments, whether financial or in resources. This underscores the importance of the pre-project phase to understand the true needs of the company.

According to the literature, the functionalities of the tower include cost control, monitoring, tracking, and visibility. Interviewed companies also emphasize the importance of collaboration, decision-making, notifications or alerts, and delivering real-time information as shown in Table 19. Yan *et al*., 2012 and Ye, Zaraté, and Kamissoko, 2022, point out that real-time SCCT requires constant monitoring to gain predictability and take preventive actions, which implies dependence on 24-hour updates and additional costs. Costs and partnerships with carries are some of the reasons for not implementing a real-time tower.

Table 19 - SCCT Functionalities

SCCT Functionalities								
Companies	**Visibility**	**Collaboration**	**Monitoring**	**Decision Making**	**Risk Management**	**Cost Control**	**Alerts**	**Real Time Data**
A	✓	✓	✓	✓	✓	✓		✓
B	✓	✓	✓	✓		✓		
C	✓	✓	✓	✓		✓		

Source: Author (2023).

All three companies refer to the visibility of the Control Tower, corroborating with Liotine's (2019) assertion that visibility is a fundamental capability of an SCCT. Company A mentions that some of its upcoming initiatives include the implementation of intelligent features, such as machine learning, enabling the identification of bottlenecks and deviations through alerts/messages in the Control Tower.

The lack of collaboration Wislack (2020) between areas, carriers, and logistics operators can significantly affect data accuracy, especially in situations with many databases. Another critical factor is decisions made strategically, tactically, and operationally (Gerrits; Topan; Van Der Heidjen, 2022) presented in Table 20. Company A uses the tower for daily operational decisions but conducts monthly evaluations of services provided by logistics operators. Companies B and C depend on the tower area; B, with a focus on Material Planning, monitors indicators daily, while decisions are made by the manager tactically. Strategic decisions are also made viable and presented in a monthly forum.

Table 20 - SCCT Decision Making

SCCT Decision Making			
Companies	**Strategically**	**Tactically**	**Operationally**
A		✓	✓
B	✓	✓	✓
C		✓	

Source: Author (2023).

Although KPIs are not exactly functionality, their importance is equal to the others, as they are crucial for the tower controllers' decisions. Overall, KPIs can vary depending on the business type and the area present in the tower. Among the interviewed companies, the main indicators are: OTIF, Volume/Freight, inventory level, loading times, waiting times, dead freight, and WMAPE.

Among the interviewed companies, the only one that had a physical control tower with, which means a room with visualization screens and a 24-hour monitoring team, was Company A. The remaining companies conduct online. The literature does not mention the need for a physical space for operational control.

For the successful implementation of an SCCT, it is crucial to employ technologies capable of integrating and automating data. As highlighted by Liotine (2019), Vlachos (2021), Ye; Zaraté; Kamissoko (2022), and Le Roch et al. (2014), the key technologies that must be part of the tower are IoT, artificial intelligence, and big data/data analysis. In practice, systems such as ERP, cloud computing, cameras, WMS, and analysis tools are indispensable and should not be overlooked. These technologies can be categorized as essential, meaning those that are indispensable for the effective operation of the tower: GPS, data analysis, cloud computing, and ERP system. Additionally, other technologies, such as IoT, WMS/TMS, machine learning, and artificial intelligence, can be integrated into the tower to enhance information accuracy. The technologies found in the literature and in companies are presented in Table 21.

Table 21 - SCCT Technologies

SCCT Technologies							
Companies	**Data Analytics**	**ERP**	**WMS**	**TMS**	**Cloud Technology**	**Cameras**	**GPS**
A	✓	✓	✓	✓	✓	✓	✓
B	✓	✓			✓		
C	✓	✓	✓	✓	✓		✓

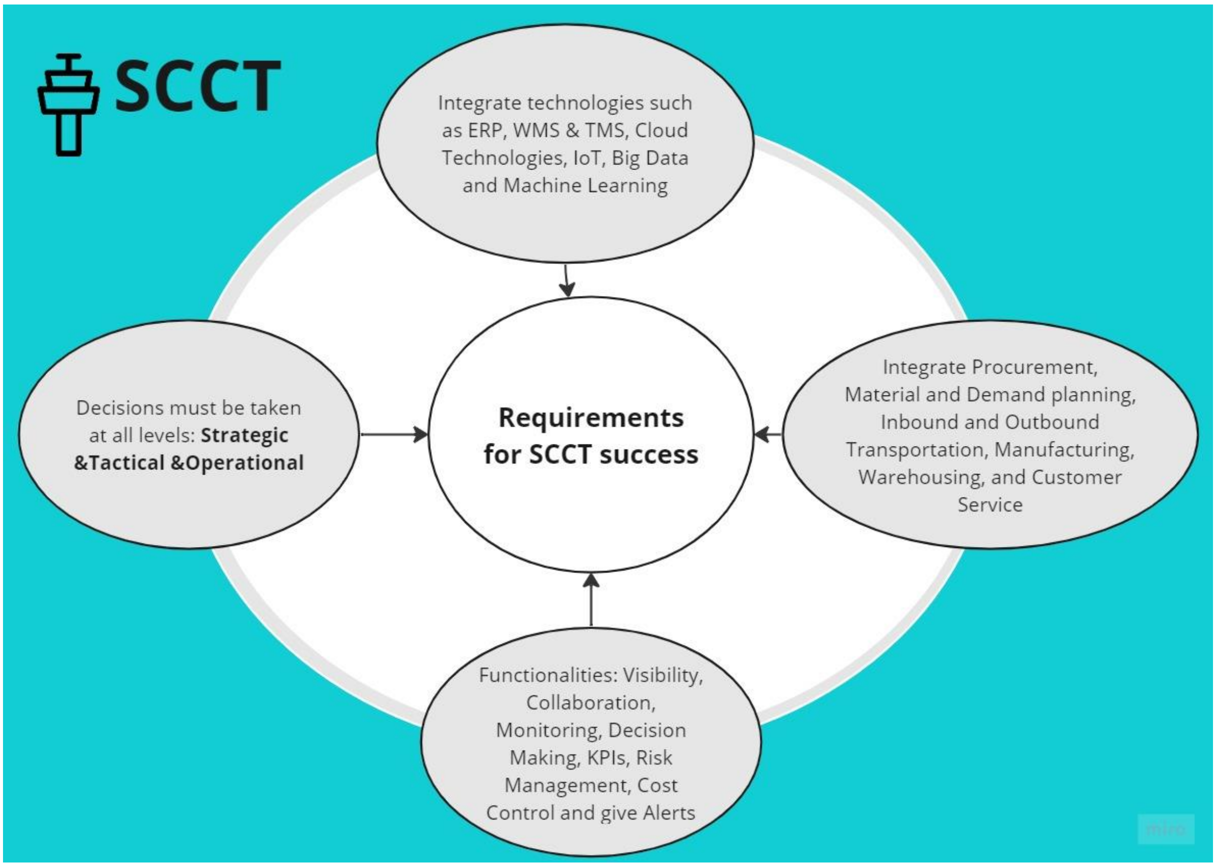
Source: Author (2023).

However, it is essential to emphasize that to achieve a real-time, efficient, and intelligent SCCT, it is imperative that all these technologies are implemented and operating in an integrated manner. This holistic approach is crucial to ensure synchronization and effectiveness of real-time operations, providing a comprehensive and agile view of the supply chain.

6. REQUIREMENTS FOR IMPLEMENTING THE CONTROL TOWER

Few frameworks were found in the literature. Those identified only present their structure as shown by Ye, Zaraté and Kamissoko (2022) or the tactical and operational decision-making shown by Topan *et al.* (2020). None presented all tower interfaces. Therefore, the interviews conducted with the three companies, along with references found in the literature, allowed the creation of connections regarding what are the requirements for SCCT success, as illustrated in Figure 7.

Figure 7 - Framework of requirements for a SCCT success



Source: Author (2023).

For the implementation of an SCCT it is necessary to have a well-structured and connected supply chain. An End-to-End tower enables a broad view of processes, consequently allowing better control of goods movements and better decision-making. The main areas integrated into the SCCT include procurement, material and demand planning, inbound and outbound transportation, manufacturing, warehousing, and customer service. For its connection, it is important to have an ERP system capable of processing all these data. Through an API, it is possible to extract data from the software and integrate it with cloud technology, allowing the storage of a large amount of big data without compromising performance due to hardware memory. Electronic data interchange (EDI) ensures good optimization in logistic operations by exchanging information between systems electronically and standardized, but it can be replaced by IoT technology especially when it comes to tracking. Another essential technology for the SCCT is machine learning, which uses algorithms to predict future events and to generate alerts supporting decision-making processes. Although not mandatory, artificial intelligence is another technology that has been evolving even more and can contribute significantly to route optimization, supplier management, and demand forecasting.

In addition to the areas and technologies, another important factor for the SCCT is management skills. When it comes to supply chain management decision-making can be divided into three levels: strategic, tactical, and operational. Strategic decisions set the overarching direction, usually months ahead of the current observation. Tactical decisions detail how to achieve those goals, usually assisted by KPIs. At least, operational decisions involve the daily tasks to implement the plans effectively. Generally, the decisions have an immediate effect and are based on real-time information. The SCCT's capabilities contribute to better decision-making at each of these levels, leading to a more responsive and adaptive supply chain.

Finally, the Supply Chain Control Tower provides real-time visibility throughout process monitoring and collaborative communication. Rooted in data-driven decision-making, it empowers organizations to navigate strategic, tactical, and operational choices with precision bolstered by comprehensive Key Performance Indicator (KPI) tracking. The SCCT goes beyond reactive measures, incorporating advanced risk management to anticipate and address potential challenges, enhancing overall supply chain resilience. With cost control features optimizing expenditures and real-time alerts for immediate issue recognition, the SCCT serves as a centralized hub, elevating agility and efficiency across the entire supply chain ecosystem.

7. CONCLUSIONS

The main objective of this study was to define supply chain control tower based on a systematic literature review, identifying the gaps between the literature and application in industries.

According to the literature and the interviews, SCCT is a centralized hub that leverages real-time data, integrated information systems to coordinate, monitor, and manage end-to-end supply chain operations. Despite the theme being Supply Chain Control Tower none of the interviewed companies fit this classification.

In the literature, few articles on control towers were found with a higher number of publications in recent years, indicating the novelty of theme even on an international scale. From the interviews, it was observed that companies are generally aligned with what the literature discusses regarding the involved areas, technologies, and functionalities of a control tower. However, for the tower achieve its ultimate purpose of providing visibility for real-time decision-making, it is recommended that Companies B and C evaluate if their tool plans align with their objectives.

Finally, a framework is proposed outlining the successful requirements for implementing a supply chain control tower based on literature findings and on-site observations. A SCCT needs integration with a robust ERP system and cloud technology to ensure seamless data flow, with electronic data interchange and emerging technologies like IoT optimizing operations. In addition, Machine Learning and artificial intelligence are technologies that can offer a huge efficiency across the entire supply chain. When looking for areas involved it is essential for a well-structured and connected supply chain, consider procurement, planning, transportation, manufacturing, warehousing, and customer service areas. For managerial skills, it must be very clear to categorize decisions into strategic, tactical, and operational levels. The SCCT's real-time visibility, supported by advanced risk management and cost control, serves as a centralized hub, elevating agility and efficiency across the entire supply chain ecosystem.

For future studies, the author suggests approaches in:

- Carry out new searches in the databases with the keywords found in VosViewer;
- Interview more companies especially those that have implemented a Supply Chain Control Tower;

- Build a step-by-step framework for implementing a Supply Chain Control Tower.

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ANNEX A - QUESTIONNAIRE

1. What is the main motivation to implement SCCT?
2. What were the main functionalities considered in the SCCT project?
3. How was the SCCT implementation process executed?
4. What are the key advantages or positive outcomes of its usage?
5. Which specific operational areas or domains are monitored within the tower?
6. Which Key Performance Indicators (KPIs) are under continuous monitoring within the tower?
7. How is the tower tracked, and who holds decision-making authority?
8. Are there any limitations or constraints associated with the control tower utilization? For instance, updates, gaps, or manual inputs?
9. Which systems and technologies are utilized in the Control Tower?
10. Which future potential opportunities does the company envisage with the SCCT ?