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TORRES DE CONTROLE NA CADEIA DE SUPRIMENTOS: REVISÃO SISTEMÁTICA E CATEGORIZAÇÃO

CONTROL TOWERS IN SUPPLY CHAINS: SYSTEMATIC REVIEW AND CATEGORIZATION

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TORRES DE CONTROLE NA CADEIA DE SUPRIMENTOS: REVISÃO SISTEMÁTICA E CATEGORIZAÇÃO

Objetivo do estudo
Desenvolver uma categorização abrangente das torres de controle na gestão da cadeia de suprimentos, definindo os principais processos da cadeia de suprimentos e revisando sistematicamente a literatura existente para esclarecer os papéis, capacidades e áreas de foco das torres de controle.

Relevância/originalidade
Esta pesquisa aborda a falta de uniformidade na identificação e categorização das torres de controle, oferecendo uma estrutura nova que melhora a compreensão de suas variadas aplicações e papéis em diferentes processos da cadeia de suprimentos.

Metodologia/abordagem
Foi realizada uma revisão sistemática da literatura usando os bancos de dados Scopus e Web of Science, seguindo o protocolo PRISMA, para identificar e categorizar as torres de controle com base nos principais processos da cadeia de suprimentos.

Principais resultados
O estudo identifica três categorias principais de torres de controle: gestão de transporte, gestão de inventário, e gestão da cadeia de suprimentos como um todo, destacando os diversos papéis e integrações tecnológicas.

Contribuições teóricas/metodológicas
Fornece uma estrutura atualizada para categorizar torres de controle, abordando ambiguidades em suas definições e aplicações, e oferecendo insights sobre seus papéis em diferentes processos da cadeia de suprimentos.

Contribuições sociais/para a gestão
A pesquisa oferece insights gerenciais para a implementação de torres de controle, otimizando a tomada de decisões e aproveitando tecnologias avançadas, como IA e blockchain, para melhorar as operações da cadeia de suprimentos.

Palavras-chave: Gerenciamento da Cadeia de Suprimentos, Torres de Controle, Torre de Controle da Cadeia de Suprimentos, Revisão Sistemática, Categorização

CONTROL TOWERS IN SUPPLY CHAINS: SYSTEMATIC REVIEW AND CATEGORIZATION

Study purpose
Develop a comprehensive categorization of control towers in supply chain management by defining key supply chain processes and systematically reviewing existing literature to clarify control tower roles, capabilities, and focus areas.

Relevance / originality
This research addresses the lack of uniformity in control tower identification and categorization, offering a novel framework that enhances understanding of their varied applications and roles across different supply chain processes.

Methodology / approach
A systematic literature review was conducted using Scopus and Web of Science databases, following the PRISMA protocol, to identify and categorize control towers based on key supply chain processes.

Main results
The study identifies three primary categories of control towers: transportation management, inventory and warehouse management, and broader supply chain management, highlighting diverse roles and technological integrations.

Theoretical / methodological contributions
Provides an updated framework for categorizing control towers, addressing ambiguities in their definitions and applications, and offering insights into their roles across different supply chain processes.

Social / management contributions
The research offers managerial insights for implementing control towers, optimizing decision-making, and leveraging advanced technologies like AI and blockchain for improved supply chain operations.

Keywords: Supply Chain Management, Control Towers, Supply Chain Control Tower, Systematic Review, Categorization

CONTROL TOWERS IN SUPPLY CHAINS: A SYSTEMATIC REVIEW AND CATEGORIZATION

1 Introduction

After COVID-19 pandemia, when disruptions had affected directly and indirectly the Supply Chain (SC) worldwide, end-to-end visibility has been required to reinforce the resilience (Vlachos, 2023). Patsavellas *et al*. (2021) argue that visibility is a key business enabler within an organization and its partners, being a capability that drives operational performance improvement.

Among the pool of technological tools of industry 4.0 that can support visibility, the control towers (CT) were gaining attention in the past decades, since they are paving the way toward the development of large-scale digital platforms and new models that efficiently integrate resources to provide real-time visibility of the whole supply chain (Patsavellas *et al*., 2021; Maheshwari *et al.*, 2023; Wycislak and Pourhejazy, 2023).

The benefits of CT implementation are numerous. For Sharabati *et al.* (2022), CTs improve organizational performance, while Chen *et al*. (2024) and Vlachos (2023) highlight that they contribute to organization’s responsiveness and resilience as it enables supply chain orchestration and decision optimization. Moreover, Banker (2023) affirms that, by using edge technology (such as digital twins), control towers can support supply chain agility. Patsavellas *et al*. (2021) states that cost savings, increased efficiency, better consumer experience and improved organizational models are the four key benefits of CTs.

The concept of a control tower is to provide real-time information to everyone who needs it to make informed decisions in their roles (Handfield *et al.*, 2020), allowing smooth monitoring and management of the rapidly changing supply and demand matrix (Maheshwari *et al*., 2023). As a result, CTs foster a coordinated network to continuously handle complexity and achieve performance levels that would be difficult for humans to manage on their own (Liotine, 2019).

In fact, a CT results from the synergy of organizations (people), technology and process (Patsavellas *et al*., 2021; Maheshwari *et al.*, 2023; Vlachos, 2023). Its operation is based on the use of technologies (i.e. internet of things and cloud platforms) that integrate and process real-time data from various sources to enable a centralized planning and control (Wyciślak and Pourhejazy, 2023), ultimately allowing more accurate decision-making (Hasbum *et al*., 2022).

However, CTs in the supply chain context are not all equal. They can vary in terms of SC process encompassed, since they can be customized to specific needs and areas of the organization (Kulkarni, 2023). For instance, some of them focus on transportation (Alacan and Sencer, 2021), while others focus on inventory (Hekimoğlu *et al*., 2022). A third group considers both previous other supply chain processes, such as procurement and manufacturing, being more accurately termed as Supply Chain Control Towers (SCCT).

Moreover, many studies label CTs as Supply Chain Control Towers (i.e., some authors mention the labels SCCT and Services CTs as synonymous) although their scope does not really encompass all the supply chain operational in their physical and logical execution (Liotine, 2019), while other choose unique names not previously adopted in literature, i.e. Material Control Tower (Handfield *et al.*, 2020).

This lack of uniformity in identifying and label the Control Towers in supply chain context prejudices the development of the literature since it can lead to misunderstanding in terms of control tower’s characterization, operation and definitions. In this sense, as a first effort aiming to shed light on this issue, the following research question was proposed: Which are the main focus areas of control towers in the supply chain context?

The main goal of this research is to develop a comprehensive and updated categorization of control towers in the supply chain context by defining core supply chain processes and systematically reviewing existing literature. This categorization aims to clarify the varied focus areas of control towers, addressing the current lack of uniformity in their identification and labeling, and enhancing understanding of their roles and capabilities in supply chain management.

In answering the research question, two specific objectives were defined. Firstly, define key supply chain components that will be used to group the control towers. Secondly, conduct a systematic review of the literature on control towers in the supply chain context, using Scopus and Web of Science databases and following the PRISMA protocol. As a result, each control tower's focus found would be properly identified and categorized.

In this sense, our main contribution to the extent literature is to propose an up-to-date categorization of control towers in the supply chain context due to the process that they encompass. Additionally, this research offers managerial implications by providing insights into effectively implementing control towers, optimizing decision-making, and leveraging advanced technologies for improved supply chain operations.

From this Introduction, the research is organized as follows. Section 2 reviews the existing literature on supply chain components and control towers. Section 3 presents the research design as well as the method intended to be employed in this research to reach its objectives. Section 4 discusses the study findings including the control tower main areas and managerial implications. Section 5 presents the conclusion, limitations and future research areas.

2 Literature Review

This section briefly explores the essential processes of supply chain management and the evolving role of control towers within this context.

2.1 Supply chain key process

Supply chain management is defined as the systemic and strategic coordination of traditional business functions, and the tactics used across these functions within a company and among businesses in the supply chain aims to enhance the long-term performance of individual companies and the supply chain (Mentzer *et al*., 2001).

In this context, according to Blachard (2010), the traditional core processes of supply chain management are demand planning, procurement, manufacturing, transportation, distribution and warehousing, site selection, globalization and customer service. Among other relevant elements, Chopra and Meindl (2013) also consider demand planning, transportation, inventory, transportation, procurement and manufacturing as key processes.

Therefore, for the sake of this research these six supply chain processes, found in both of these foundational references of supply chain management, will be used as the framework for categorizing the control towers evidenced on the literature review.

2.2 Control Towers in the supply chain context

The concept of control towers in supply chain is inspired by aviation, where controllers oversee aircraft traffic both in the air and on the ground, by companies that develop logistics control towers to manage transportation routes (Vlachos, 2023). By the time, this restricted employment was overcome by encompassing other supply chain processes under the umbrella of the control tower due to the benefits of such technology.

Recently, when globalization have increased the complexity of the supply chains around the world and their weaknesses had been shown by the COVID-19 crisis, the need for CT's capabilities of centralized real-time planning and control (Wyciślak and Pourhejazy, 2023) to support managers' decision-making process in supply chain management was reinforced (Gerrits *et al*., 2022; Ma *et al*., 2023).

They consist of centers of excellence that can integrate data from various sources to manage the supply chain information flow (Wyciślak and Pourhejazy, 2023), providing end-to-end visibility (Sharabati *et al*., 2022) and allowing a real-time view of the entire supply chain environment, and leading to more accurate decision-making (Vlachos, 2023).

As a result, it provides potential solutions by ensuring all stakeholders have access to the same information (Maheshwari *et al*., 2023) and allowing managers to focus on important leverage points rather than the details of complex daily transactions (Hekimoğlu et al., 2022), ultimately improving profitability (Liotine, 2019).

Moreover, CTs enable cross-functional teams to collaborate with suppliers in addressing the most complex and urgent issues via a shared dashboard (Maheshwari *et al.*, 2023). It is possible because CTs break down the data silos from various non connected systems to provide visibility over the changes on planning schedules, as well as pointing out where improvements are needed and how it could be done (Kulkarni, 2023).

Therefore, as shown above, control towers have indeed begun focusing on transportation, but the development of new technologies have made them able to involve other supply chain process since the integration among different sectors of the same company as well as other companies of the same chain was possible, ultimately reaching the level of provide visibility of the entire supply chain in real-time.

3 Research Methodology

A systematic literature review about control towers in the supply chain context was conducted to support the Control Towers' focus areas identification. Following the methodology of Rethlefsen *et al.* (2021), Figure 1 displays the PRISMA that illustrates the review process. To ensure a high-quality range of peer-reviewed journals, all eligible studies in the Scopus and Web of Science databases were included within the research scope. As a result, the researcher selected 24 articles from amongst 99 papers that were found in the databases.

The systematic review involved a comprehensive search for studies on control towers and supply chains, using the specific keywords presented below. First, aiming to identify which keywords could relate to control towers in the supply chain context, a generic search using just TITLE-ABS-KEY ("supply chain*" AND "control tower*") on the scopus database. The objective was to enlarge the range of searches on the databases with keywords that were not obvious, although are relevant to the intended research area.

From this initially non-systematic search other labels for CTs in the SC context were identified, such as Service and Transportation Control Towers. As a result, the initial keywords were improved to the following: TITLE-ABS-KEY (("digital*" OR "logistic*" OR "supply chain*" OR "service*" OR "transport*") AND "control tower*").

Finally, when the search for the systematic review was made, a huge number of articles from the aviation industry (as traffic control), which are not related to the sake of this research. It is explained by the fact that the concept of a Supply Chain Control Tower is derived from the aviation industry, where air traffic controllers oversee and direct the movement of aircraft both in the sky and on the ground (Vlachos, 2023).

Thus, to solve this issue, the search of terms was complemented by adopting exclusion keywords, resulting in the final following keywords: TITLE-ABS-KEY (("digital*" OR "logistic*" OR "supply chain*" OR "service*" OR "transport*") AND "control tower*" AND NOT ("air traffic" OR "airport")). Both searches were done on May 6, 2024, around 1:45 pm on both databases.

The exclusion criteria include relevance and duplication. Relevance for the sake of the research was determined by reading the abstract and conclusion of downloaded articles from different databases. Duplicated articles were also excluded by manual detection. Additionally, books, reports, thesis, dissertation, working papers and conference papers were not considered.

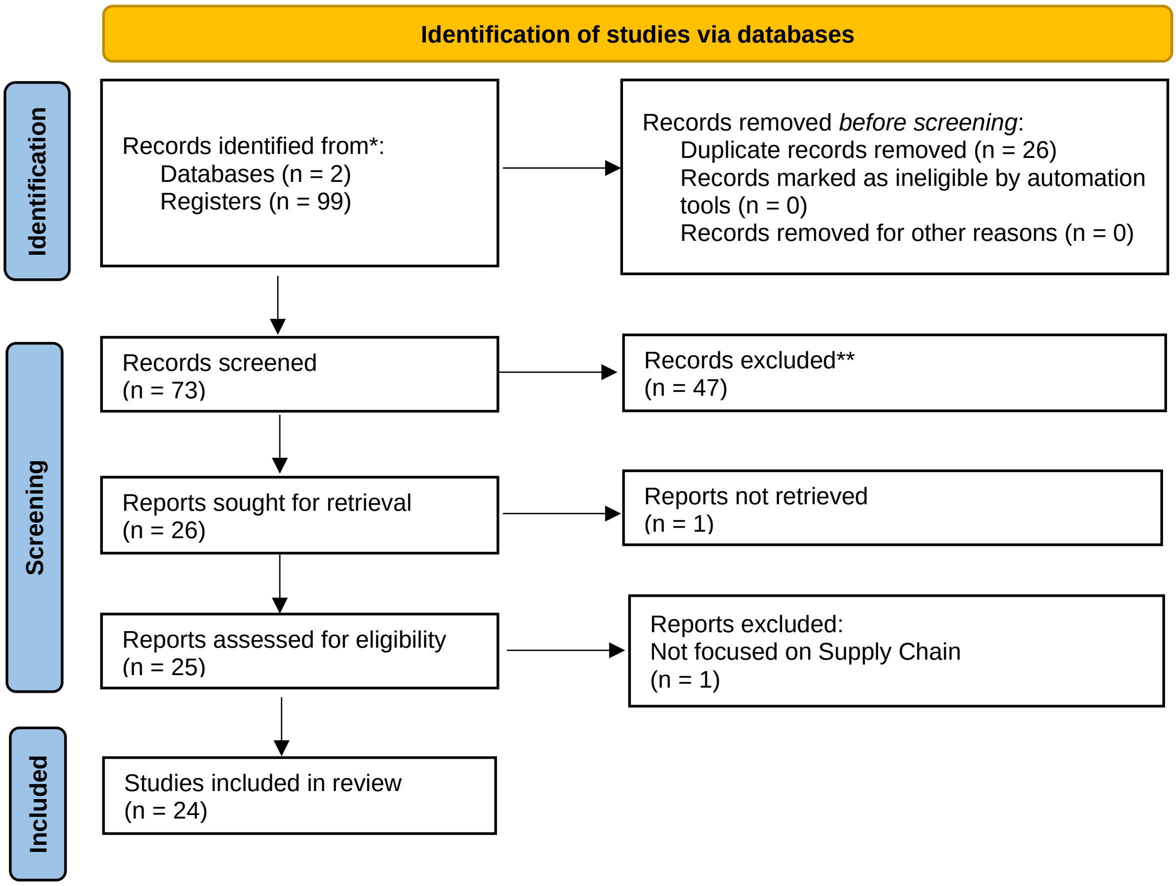

Fig. 1. The PRISMA obtained in the review process.

4 Research results

This section examines the results of a systematic literature review on control towers in supply chain management, highlighting the growing academic interest and diversity in control tower applications from 2020 to 2024. The review identifies nine distinct labels used for control towers, indicating a lack of consensus on their definitions and focus areas, which range from transportation management to more comprehensive supply chain solutions. The findings reveal three primary categories of control towers: those focused on transportation, inventory and warehouse management, and broader supply chain management. This categorization aids in understanding the varied roles and capabilities of control towers. The chapter also discusses managerial implications, emphasizing the need for clear scope definition and consideration of advanced technologies like AI and blockchain in control tower implementations to enhance decision-making and operational efficiency.

4.1 Analysis of Results

The literature review allowed the identification of the increasing interest in the study of control towers in supply chain contexts (Chen *et al*., 2024) as well as its novelty (Kulkarni, 2023). As it is possible to identify in Figure 1, most of the articles related to the main subject of this study were published from 2020 to 2024 (88%).

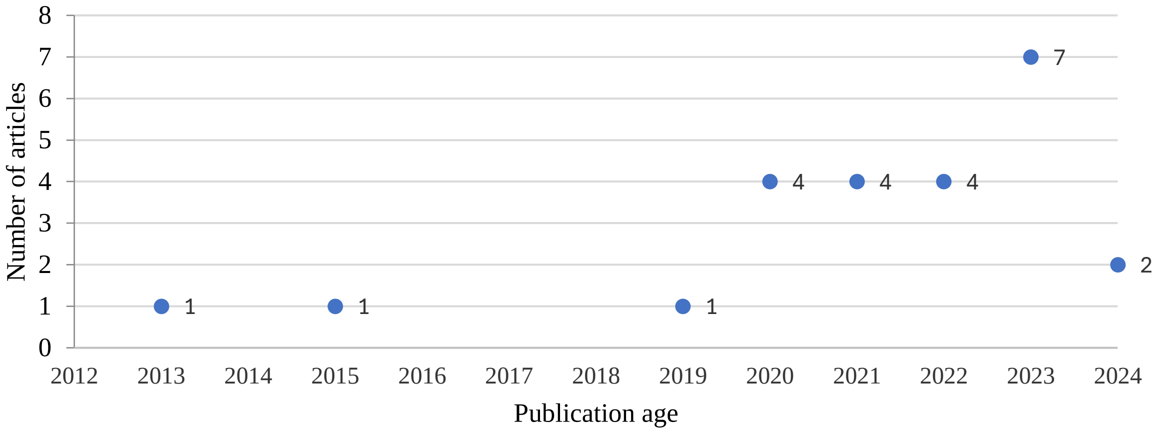

Fig. 2. CT papers distribution by age of publication.

Following the evidenced novelty of the theme, there were also found nine different labels among the twenty-four articles studied (see Table 1), suggesting the above-mentioned ambiguity in terms of what each control tower refers to. For example, both Wycislak (2023), Guidani *et al.* (2024) adopted the label Control Tower, but while the former focuses solely on transportation, the latter has a broader approach encompassing other supply chain processes.

Table 1 - The different nomenclatures of Control Towers

Labels	Authors
Control Tower	Chen *et al.* (2024), Wycislak (2023), Guidani *et al.* (2024), Liotine (2019), Hasbum *et al.* (2022), Roch *et al.* (2015), and Kulkarni (2023).
Supply Chain Control Tower	Maheshwari *et al.* (2023), Vlachos (2023), Wyciślak and Pourhejazy (2023), Sharabati *et al.* (2022), Patsavellas *et al.* (2021) and Banker (2021).
Service Control Tower	Topan *et al.* (2020), Gerrits *et al.* (2022), Ma *et al.* (2023) and Duarte *et al.* (2023).
Transportation Control Tower	Maneengam and Udomsakdigool (2020) and Alacan and Sencer (2021).
Other	Digital Control Tower - Vanvuchelen *et al.* (2020).
	Material Control Tower - Handfield *et al.* (2020).
	İnventory Control Tower - Hekimoğlu *et al.* (2022).
	Logistics Control Tower - Maneengam and Udomsakdigool (2021).
	Supply Chain Quality Control Tower - Ji *et al.* (2013).

In the early 2010s, significant research efforts were focused on defining and understanding the architecture of Control Towers (CTs) in supply chain management, as well as identifying the essential connectivity components that facilitate their operations. Ji *et al.* (2013) pioneered the discussion by proposing a CT framework that enhances quality control within the CT owner's domain and extends this control across its supply chain partners.

Their work detailed a five-layer architecture that supports traceability and information management through the use of Radio-Frequency Identification (RFID) technology and other sensor systems, laying a foundational theoretical basis for CT functionality.

Corroborating RFID’s role in allowing item-level traceability, Roch *et al*. (2015) explores the development and implementation of new logistics models (i.e. control towers) leveraging this technology and a standardized tracking system to manage returnable transport items within varied systems used by different supply chain partners in an open network. The results show significant improvements in the visibility, efficiency, and operational management of these reusable assets, but it also acknowledges the need to address various technical and organizational challenges to fully realize its benefits.

Pioneering in considering artificial intelligence and machine learning in control towers, Liotine (2019) developed a theoretical paper estimating the possible challenges and benefits of implementing these technologies in the pharmaceutical industry. The study found that these technologies can elevate real-time information gathering, analysis, and decision-making, evolving basic operational modes to strategic decision-making levels in CTs. On the other hand, they can also introduce issues such as collaboration and data sharing across supply chain tiers and cross-system interoperability, among others.

The 2020-decade papers have two clear trends related to control towers dedicated to specific supply chain components, namely transport and inventory. Analyzing the former, this emphasis is clearly demonstrated by Maneengam and Udomsakdigool (2020) and Alacan and Sencer (2021) by having chosen the label Transportation Control Tower (TCT). Moreover, other works that did not adopt this name have also restricted their approaches to transport management (Vanvuchelen *et al.*, 2020; Maneengam and Udomsakdigool, 2020; Wyciślak and Pourhejazy, 2023; Wycislak, 2023; Kulkarni, 2023).

Although the focus on transportation orchestration and visibility in control towers correspond to the beginning of its use in the supply chain context (Vlachos, 2023), all of the studies found with this focus are recent (from 2020 up to now). However, this apparent dichotomy is not an issue since the recent case study realized by Wycislak (2023) had shed light on the necessity to better comprehend the dynamics of CT implementation process to guarantee the desired visibility level reach, demonstrating that there is still room for new research in this field.

Wyciślak (2023) investigated the tensions and competition amongst platform owners and complementors in the implementation of a control tower dedicated to overseeing transportation management. The study showed the lack of attention given to understanding the governance mechanisms and tensions of CT, particularly in transportation networks where subcontracting is prevalent. It emphasizes the need for research on how platforms balance conflicting tensions such as openness vs. control and collaboration vs. competition with complementors.

Solving the problem of the lack of trust among the partners in the trucking industry (shippers, carriers and freight forwarders) identified by Wyciślak (2023) is the focus of the two articles that adopted the TCT label. Maneengam and Udomsakdigool (2020) enhance TCT’s role as a solution to foster trust among shippers and carriers in bulk transportation that were unwilling to share information as they worry about partner’s asymmetry of power. Likewise, Alacam and Sencer (2021) analyze the benefits of blockchain usage in TCTs to solve the lack of trust generated by broker’s interest when connecting shippers and carriers.

Other papers worked on CT operations optimization. For example, Wyciślak and Pourhejazy (2023) developed a conceptual model for identifying an Intelligent Dock Booking (IDB) system implementation requirement, as part of a CT setup, and assessing its impact on supply chain performance. The findings indicate the importance of real-time data integration, dynamic responsiveness, automated scheduling and operational preconditions as key requirements to allow the improvement of the supply chain's overall efficiency.

Finally, Kulkarni (2023) explores how CTs can enhance end-to-end supply chain visibility in container terminal operations. By integrating and analyzing real-time data from various sources such as vessel management, terminal operations, trucking companies, and customs, Kulkarni (2023) suggests that CTs can help in predicting potential issues and suggesting corrective actions to optimize terminal performance. These benefits will be maximized according to availability of real-time data and collaboration among partners.

In the field of CTs focused on inventory management, there is a group of papers that name the CT as a Service Control Tower (SCT). They made it in the specific context of spare parts supply chains (Ma *et al*., 2023), where after-sales services are provided by original equipment manufacturers and third-party service providers that operate complex spare parts supply networks (Gerrits *et al.*, 2022). In such a context, control towers can perform two crucial roles: providing advance warnings of potential future stockouts and making decisions to expedite repairs (Hekimoğlu *et al.*, 2022).

Introducing this specific label, Topan *et al.* (2020) have provided a comprehensive review of the operational logistics involved in spare parts service within SCTs. The authors identify key operational decisions, practical challenges, and promising research directions in this field. Moreover, their review emphasizes the need for integrating tactical and operational planning, managing alerting messages, and leveraging advanced analytics for improved decision-making.

Gerrits *et al.* (2022) and Ma *et al*. (2023) developed optimization studies addressing the topics for future studies and gaps identified by Topan *et al.* (2020). The former used operational proactive interventions to improve the performance based on SCT's real-time status information, finding that in general operational interventions are more effective in the SCs downstream. The latter explores the use of real-time replenishment information for admission control in a capacitated supply system by developing models and algorithms to optimize inventory management.

Despite Duarte *et al.* (2023) having adopted the same label because it is the same after-sales maintenance field, their study is not directly related to Topan *et al.* (2020). In this sense, it consists of an empirical approach to improving spare parts consumption in the repair process through a learning-to-rank method. The authors propose a data-driven method for SCTs to support the automatic checking of spare parts consumption. By simulating the passage of time and training multiple machine learning models, the study aimed to identify deviations in spare parts usage and enhance alert generation.

Lastly related to the SCT's context, the Inventory Control Tower proposed by Hekimoğlu *et al*. (2022) focuses on stockout risk estimation and repair expediting for repairable spare parts. To this end, a system designed to estimate the future stockout risk of repairable parts is presented. Additionally, they proposed a repairable inventory control system that includes repair expediting, inspection, and condemnation processes.

Still in the inventory issue, but outside the after-sales service supply chains, Hasbum *et al*. (2022) identified the Control Tower, among other technologies, as a key enabler of inventory control used during the pandemic of COVID-19, which allowed companies to reach the desirable visibility while having a better understand of the real-time environment panorama and thus make more accurate decisions on their supply chains.

Notwithstanding, the technological development allowed the extension of CT's initial boundaries to other supply chain management areas. Consequently, properly labeled SCCT can nowadays provide visibility and orchestration on procurement, manufacturing, inventory, transport, risk, and financial management, among others. In this context, while many theoretical papers have discussed SCCTs capabilities and benefits (Banker, 2021; Sharabati *et al.*, 2022; Maheshwari *et al.*, 2023; Guidani *et al.*, 2024), only Vlachos (2023) have done empirical research about the SCCT implementation.

Sharabati *et al.* (2022) investigate impact of SCCT on the Competitive Advantage (CA) of the Jordanian Pharmaceutical Manufacturing Industry. To reach its objective a SCCT framework encompassing demand planning, procuring and sourcing, operations, in-bound and out-bond logistics and inventory and warehousing was established. The findings indicate that SCCT has a significant positive effect on quality, cost, reliability and responsiveness components of CA, while did not have a significant effect on innovation.

Banker (2021), Maheshwari *et al.* (2023) and Guidani *et al.* (2024) investigate Digital Tweens (DT), an accurate virtual representation of an object, process or system, in the context of SCCT. The first discussed the role of SCCT leveraged by DT in providing supply chain agility. The second explores the potential benefits of integrating DTs within warehouse management systems. The last one proposed a DT that supports decision-making by offering a comprehensive control tower designed for the agri-food ecosystem stakeholders.

Although all the mentioned authors agree about the essential roles of these technologies in modern supply chain management, they see their relation differently. Maheshwari *et al.* (2023) and Guidani *et al.* (2024) assert that once digital twins are implemented to create virtual models, SCCT can be established to centralize and coordinate the monitoring and management of these digital twin-enabled processes.

On the other hand, Banker (2021), control towers are often established first to enhance visibility and planning capabilities, then digital twins then come into play to provide a more detailed and dynamic representation of the supply chain for scenario analysis and decision-making. This dichotomy demonstrates that more study is needed to grasp the dynamics of this SCCT and DT relation.

Vlachos (2023) presents a case study on the implementation of a SCCT by a large manufacturing company transitioning from outsourcing to developing its own SCCT structure. This study outlines a three-phase implementation plan: Initiation, Live, and Continuous Improvement. It emphasizes the integration of various technology types and highlights the critical role of socio-technical interactions among the SCCT team, internal, and external stakeholders. The study identifies barriers such as system misalignment and trust issues while showcasing the improvements in supply chain visibility, flexibility, and cost control, ultimately supporting strategic decision-making and business growth.

Material Control Tower was the label chosen by Handfield *et al*. (2020) to identify a CT proposed to address the challenges the US faced in procuring and managing health supplies during the COVID-19 pandemic. In their study, the authors advocate for the creation of a CT designed to enable the public health supply chain to function through a network of repositories. This system would feature dynamic inventories and be monitored analytically under the guidance of government experts.

Despite its label, the SC components addressed by Handfield *et al*. (2020) - inventory, shipments, manufacturing, and procurement - positions this CT closely with what is commonly understood as a SCCT. Moreover, this study was the only one found that was developed in the public administration field, indicating an avenue for research.

Finally, noting the growing interest in the "control tower" approach (Chen *et al*., 2024) and the hidden pitfalls of deciding to adopt an SCCT, Patsavellas (2021) proposed an assessment tool. This tool is based on an organization's state of readiness and requirements regarding the utility of SCCT technology, as well as the maturity level of the supply chain within the organization, to aid companies in the decision-making process of whether to adopt and implement the Control Tower solution.

Table 2 – Summary of main process of each identified Control Tower

Authors	**Supply Chain Process**	**Evidence**
Alacam and Sencer (2021)	Transportation	Improves transportation efficiency, collaboration, and transparency.
Banker (2021)	Demand Planning, Inventory, Manufacturing, Transportation	Enhances forecasting accuracy, inventory visibility, production synchronization, and route optimization.
Chen *et al.* (2024)	Inventory	Optimizes inventory levels and enhances supplier and customer coordination.
Duarte *et al.* (2023)	Inventory	Optimizes spare parts inventory using data-driven approaches.
Gerrits *et al.* (2022)	Inventory	Aligns service capacity with demand to optimize inventory control.
Guidani *et al.* (2024)	Procurement, Inventory, Manufacturing, Transportation	Optimizes sourcing strategies, provides inventory visibility, and supports global operations.
Handfield *et al.* (2020)	Demand Planning, Procurement, Transportation	Enhances planning, sourcing, and logistics strategies post-COVID-19.
Hasbum *et al.* (2022)	Inventory	Explores strategies for inventory control during the pandemic.
Hekimoğlu *et al.* (2022)	Inventory	Predicts stockout risks and optimizes inventory and sourcing strategies for spare parts.
Ji *et al.* (2013)	Inventory, Transportation, Manufacturing	The quality control optimization is based on the increased visibility over the entire supply chain.
Kulkarni (2023)	Transportation	Improves container handling, equipment utilization, and reduces delays.
Liotine (2019)	Manufacturing, Inventory, Transportation	Optimizes pharmaceutical manufacturing and enhances inventory and service delivery.
Ma *et al.* (2023)	Demand Planning, Inventory	Utilizes real-time replenishment information for demand forecasting and inventory control.
Maheshwari *et al.* (2023)	Inventory	Optimizes warehouse management using digital twins.
Maneengam and Udomsakdigool (2021)	Transportation	Optimizes ship routing and procurement for sustainable shipping solutions.
Maneengam and Udomsakdigool (2020)	Transportation	Optimizes vehicle routing and logistics planning through collaboration.
Patsavellas *et al.* (2021)	Demand Planning, Transportation, Inventory	Explores the role of control towers in enhancing demand planning and logistics.
Roch *et al.* (2015)	Transportation	Explores the role of RFID in improve shipment process
Sharabati *et al.* (2022)	Demand Planning, Inventory Procurement, Transportation	Enhances supplier collaboration, inventory visibility, and service delivery.
Topan *et al.* (2020)	Inventory, Transportation	Optimizes spare parts logistics for better availability and reduced costs.
Vanvuchelen *et al.* (2020)	Inventory	Optimizes inventory replenishment and supplier coordination using advanced algorithms.
Vlachos (2023)	Demand Planning, Inventory, Procurement, Transportation	Improves forecasting, supplier management, inventory control.
Wycislak (2023)	Transportation	Improves coordination and visibility in transportation.
Wycislak and Pourhejazy (2023)	Transportation	Enhances logistics coordination through dock booking.

Some caveats should be mentioned to explain the categorization done. In some articles, more than just one process can be found, but indeed one is consequence of the improvement of the process encompassed by the control tower. For example, Hekimoğlu *et al.* (2022) mentions the sourcing optimization of spare parts in their work. However, it is understood in this research that the control tower described is focused on inventory management and has, as one of its consequences, the sourcing improvement.

The same applies to Duarte *et al.* (2023), where the control tower focused on inventory leads to procurement improvement. Moreover, it is important to mention that some articles don't state clearly which supply chain process are in fact included by their CTs, what lead the research to grasp it based on the evidence presented in article.

4.2 Discussion

The result of this literature summarized in Table 2 indicates the actual existence of three main groups of control towers in the supply chain management context. The first is related to transportation, the second to inventory and warehouse management and the third one, to the reunion of at least one of the other previous with other supply chain components, such as manufacturing, procurement and demand planning. Thus, based on the similarity of its emphases, each of the above-mentioned studies was grouped in Table 3.

Table 3 - Control Tower Focus

Focus	Authors
Transportation Management	Maneengam and Udomsakdigool (2020; 2021), Alacan and Sencer (2021), Vanvuchelen *et al.* (2020), Wyciślak and Pourhejazy (2023), and Wycislak (2023). Roch *et al.* (2015), and Kulkarni (2023).
Inventory and Warehouse Management	Topan *et al.* (2020), Gerrits *et al.* (2022), Hekimoğlu *et al.* (2022), Ma *et al.* (2023), Duarte *et al.* (2023), Hasbum *et al.* (2022), Maheshwari *et al.* (2023), and Chen *et al.* (2024).
Supply Chain Management	Guidani *et al.* (2024), Vlachos (2023), Sharabati *et al.* (2022), Patsavellas *et al.* (2021), Banker (2021), Handfield *et al.* (2020), Liotine (2019), and Ji *et al.* (2013).

This study allowed the understanding that supply chain control towers are a field of study that is in its beginning in terms of theoretical knowledge development since most of the papers were published from 2020 up to now. Due to this novelty, the main concepts embedded in the field still call for accurate definitions. Moreover, it was possible to find three focus areas of CTs, namely transport, inventory and the entire supply chain.

The grouped result show balance among the number of studies with each focus. This corroborate the statement of Vlachos (2023) that since the begging of the use of control towers in the supply chain context, their approach has been increased involving other process. It also shows that the initial focus in transportation is still a case in study in the literature, although their interest has been changing, appearing to have transport two trends.

The first is that since the transportation market is very competitive, CTs are seen as a solution to build trust among shippers and carriers so that the solutions suggested by the CT serve all partners equally. The second trend is that since the development of control towers in the supply chain context have in fact begun with the goods transportation monitoring, the papers that have focused on shipments are now mostly about CT's optimizations than in the theoretical discussion.

Among the group of control towers designed to oversee inventory management, those that adopted the SCT label are the majority, being the literature review of Topan *et al.* (2020)

the foundational paper for others works in the field of spare parts service logistics for after sales maintenance of capital goods. The last group have showcase that in all works that adopted the label Supply Chian Control Towers, transport (shipments) and inventory (and warehousing) are present combined with at least another supply chain component.

4.3 Managerial Implications

Based on the categorization done, inventory and transportation appear to be always present with another process in the more holistic control towers. This can be used by managers in supporting their decision on which areas should be considered in their control tower's project.

In this sense, the diverse nomenclatures and focus areas of control towers highlight the need for managers to clearly define the scope and objectives of control tower implementations within their organizations and the main stakeholders. By understanding the specific processes and capabilities that each type of control tower offers, managers can design projects that align with organizational goals and address key supply chain challenges.

Moreover, the increasing interest in incorporating advanced technologies like artificial intelligence, machine learning, and blockchain within control towers presents managers with opportunities to innovate and enhance supply chain operations. However, these technologies should be carefully analyzed due to its high cost (Patsavellas *et al.*, 2021). In this context, Finally, the framework proposed by Patsavellas *et al.* (2021) appears to be a useful tool to support the analysis of control tower implementation validity.

5 Conclusion

This research intended to address the lack of uniformity in the identification and labeling of control towers in the supply chain context. By systematically reviewing the existing literature, we developed a comprehensive categorization of control towers based on key supply chain processes. Our study highlights the critical role control towers play in enhancing visibility, coordination, and decision-making across various supply chain functions.

The analysis revealed three primary categories of control towers: those focused on transportation management, inventory and warehouse management, and a broader category encompassing multiple supply chain processes such as procurement, manufacturing, and demand planning. This categorization clarifies the varied focus areas of control towers and addresses the ambiguity in their identification. However, as it is seen as just a first effort, to shed light on this issue, future studies should provide definitions and capabilities of the three types of control towers found.

Moreover, despite the advancements in control tower technology, several areas still need further investigation. The environmental dimensions are hardly ever mentioned, although it could be an interesting focus resulting from the capacity to real-time monitoring the supply chain and suggest corrections to improve the overall efficiency. From the few studies that consider these issues, Wyciślak and Pourhejazy (2023) cited the improvement in energy efficiency and reduction in carbon footprint as a result in the optimization of a CT with Intelligent Dock Booking System.

Another unexplored area is the public administration, being the work of Handfield *et al*. (2020), proposing a CT designed to enable the US public health supply chain to function through a network of repositories, being the only one found. In this context, since Control Towers have clear potential to deliver cost savings, increased efficiency and better consumer experience (Patsavellas *et al*., 2021) as well as foster resilience against disruptions Handfield *et al*. (2020), its implementation in public organizations is likely to result in positive outcomes.

Through this research, we contribute to the ongoing discourse on supply chain management by providing an updated framework for categorizing control towers. Our findings offer valuable insights for practitioners and researchers seeking to leverage control towers to improve supply chain operations and strategic decision-making.

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