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LEONARDO CÂMARA DE ARAUJO DA FONSECA

CONTROL TOWERS IN THE SUPPLY CHAIN CONTEXT: Concepts and capabilities

Rio de Janeiro

2025

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Master's dissertation presented to the COPPEAD Graduate School of Business, Universidade Federal do Rio de Janeiro, as part of the mandatory requirements in order to obtain the title of Master in Business Administration (M.Sc.).

Advisor: Prof. Vanessa de Almeida Guimarães, Ph.D.

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2025

DEDICATION

I dedicate this research to God and Meishu-Sama for granting me the permission to complete this important phase of my life.

I also dedicate this study to my family. My wife, Luiza, and my sons, Henrique and Bernardo, who supported me unwaveringly throughout these two years of my Master's, sacrificing our time together so I could dedicate myself to my studies.

I dedicate it as well to my parents, Luiz Eduardo and Roselee, who taught me from an early age the value and joy of learning, enabling me to achieve personal and professional milestones that were once unimaginable in our reality. Finally, I dedicate this work to my sister, Sílvia, who has always been present in my life, encouraging and supporting me to continue my journey.

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RESUMO

FONSECA, Leonardo. **Control Towers in the supply chain context:** concepts and capabilities. Rio de Janeiro, 2025. 88 pp. Dissertation (Master's Degree in Business Administration) - COPPEAD Graduate School of Business, Federal University of Rio de Janeiro, Rio de Janeiro, 2025.

A crescente demanda por maior visibilidade e controle na cadeia de suprimentos tem atraído atenção significativa para o papel das Torres de Controle (TCs). Esta dissertação visa responder a três questões-chave: definir o que é uma TC, categorizar os tipos mais comuns de TCs em cadeias de suprimento e identificar e estruturar suas capacidades. Para alcançar esses objetivos, foi empregada uma abordagem de pesquisa qualitativa, integrando uma Revisão Sistemática da Literatura, Análise de Conteúdo Qualitativa e Análise de Conteúdo Dirigida. Os resultados indicam que as TCs são sistemas centralizados que proporcionam visibilidade e controle de ponta a ponta em tempo real, integrando pessoas, processos e tecnologia, enquanto apoiam a tomada de decisões para melhorar a eficiência operacional da cadeia de suprimentos. As capacidades das TCs foram categorizadas em quatro áreas principais: Visibilidade, Alertas, Suporte à Decisão e Automação. Além disso, a pesquisa definiu três tipos principais de TCs: Gestão de Transporte, Gestão de Inventário e Armazém, e Gestão da Cadeia de Suprimentos. Essas categorias foram refinadas e validadas por meio de entrevistas com 21 profissionais da indústria. Os resultados não apenas contribuem significativamente para a literatura existente ao abordar a falta de definições e frameworks padronizados, oferecendo conceitos bem estruturados fundamentados tanto na teoria quanto na prática, além de fornecem insights aplicáveis para profissionais que buscam implementar ou aprimorar TCs em suas operações.

Palavras-chave: Torre de Controle; Cadeia de Suprimentos; Visibilidade; Definição; Capacidade; Estrutura; Análise de Conteúdo.

ABSTRACT

FONSECA, Leonardo. **Control Towers in the supply chain context:** concepts and capabilities. Rio de Janeiro, 2025. 88pp. Dissertation (Master's Degree in Business Administration) - COPPEAD Graduate School of Business, Federal University of Rio de Janeiro, Rio de Janeiro, 2025.

The growing demand for enhanced supply chain visibility and control has drawn significant attention to the role of Control Towers (CTs). This dissertation aims to answer three key questions: defining what a CT is, categorizing the most common types of CTs in supply chains, and identifying and structuring its capabilities to achieve these objectives, a qualitative research approach was employed, integrating a Systematic Literature Review (SLR), Qualitative Content Analysis (QCA), and Directed Content Analysis (DCA). Findings indicate that CTs are centralized systems that provide end-to-end visibility and control in real-time by integrating people, processes, and technology, while supporting decision-making to enhance supply chain operational efficiency. CT capabilities were categorized into four key areas: Visibility, Alerting, Decision Support, and Automation. Additionally, the research defined three primary types of CTs: Transportation Management, Inventory and Warehouse Management, and Supply Chain Management. These categories were refined and validated through interviews with 21 industry practitioners. The results not only significantly contribute to the existing literature by addressing the lack of standardized definitions and frameworks, offering well-structured concepts grounded in both theory and practice but also provide actionable insights for professionals seeking to implement or refine CTs in their operations.

Keywords: Control Tower; Supply Chain; Visibility; Definition; Capabilities; Framework; Content Analysis

LIST OF ILLUSTRATIONS

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LIST OF ABREVIATIONS

API:	Application Programming Interface
B2B:	Business to Business
CT:	Control Tower
DCA:	Directed Content Analysis
EDI:	Electronic Data Interchange
ERP:	Enterprise Resource Planning
GIS:	Geographic Information System
IoT:	Internet of Things
KPI:	Key Performance Indicator
QCA:	Qualitative Content Analysis
RFID:	Radio-Frequency Identification
SCCT	Supply Chain Control Tower
SLR:	Systematic Literature Review
SCT:	Service Control Tower
SKU:	Stock Keeping Unit
TCT:	Transportation Control Tower
TMS:	Transportation Management System
WMS:	Warehouse Management System

CONTENT

1. INTRODUCTION

The recent disruptions in global supply chains highlight the challenge of grasping the supply chain's state. It consequently leads to follow-up questions: why is this happening? And what will happen next? (Maheshwari *et al.*, 2023). The answer to these questions lies in supply chain visibility (Vlachos, 2023), a concept that has recently been in the spotlight due to its capacity to support efficient decision-making (Wycislak, 2023).

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 (Patsavellas, Kaur and Salonitis, 2021). Wycislak (2023) explains that CTs have facilitated the development of large-scale digital platforms and introduced a new approach to integrating resources for achieving real-time visibility.

A CT in the supply chain context is a centralized hub that integrates technology, processes, and people to provide visibility, control, and decision support across the supply chain (Patsavellas, Kaur and Salonitis, 2021; Sharabati, Al-Atrash and Dalbah, 2022; Maheshwari *et al.*, 2023; Vlachos, 2023; Wycislak and Pourhejazy, 2023). It combines real-time data collection, advanced analytics, and alerts to optimize supply chain performance, enabling proactive and reactive interventions (Topan *et al.*, 2020; Chen, Cohen, and Lee., 2024).

Acting as an inter-organizational platform, CTs can monitor the flows of goods, information, and finances while fostering collaboration among stakeholders to mitigate risks and improve efficiency (Liotine, 2019; Maneegam and Udomsakdigool, 2021), ultimately leading to more accurate decision-making (Hasbum *et al.*, 2022) and reducing inefficiencies (Kulkarni, 2023).

CTs can provide numerous benefits, such as enhanced responsiveness, enabling rapid adjustments based on real-time information and scenario simulations (Banker, 2023; Chen, Cohen, and Lee., 2024). They can also increase resilience by identifying and mitigating risks before they escalate into significant disruptions (Handfield *et al.*, 2020; Sharabati, Al-Atrash and Dalbah, 2022) and promote agility by adapting operations to unexpected changes in demand or supply (Maheshwari *et al.*, 2023; Vlachos, 2023).

Despite their proven benefits, the adoption of this technology tool remains limited (Patsavellas, Kaur, and Salonitis, 2021). One possible explanation lies in the lack of clarity surrounding the CTs concepts. Academic literature still lacks a standardized and widely accepted definition of CTs, leading to fragmented interpretations of their scope and capabilities (Topan *et al.*, 2020).

Reflecting the novelty of the topic (Wycislak and Pourhejazy, 2023), many scholar - including Topan *et al.* (2020), Gerrits, Topan, and van der Heijden (2022), Kulkarni (2023), and Vlachos (2023) - rely on consulting firms like Capgemini and Accenture for definitions rather than academic sources. In fact, 20% of the academic papers investigated in this dissertation explicitly define CTs by using a consulting firm definition, indicating that non-academic sources play a role in the discourse. While this reliance is not inherently problematic, it underscores the absence of a robust, peer-reviewed framework for understanding CTs.

Moreover, Fonseca and Guimarães (2024) identified nine different labels used to describe CTs in the literature which reflects a lack of consensus in the area. This proliferation of terms illustrates that, despite the theory being in its early stages (Kulkarni, 2023), researchers have already taken different directions when conceptualizing on the topic. This fragmentation suggests that while CTs are recognized as a relevant tool, there is no harmony in their main concepts. This lack of standardization hinders both theoretical development and practical applications.

In addition to the need for a more precise definition, there was not found any structured framework that defines CTs' capabilities in literature. Some researchers emphasize visibility as the core function (e.g., Vlachos, 2023; Banker, 2021), while others highlight automation (e.g., Patsavellas, Kaur, and Salonitis, 2021) or predictive analytics and decision support (e.g., Liotine, 2019; Topan *et al.*, 2020). These variations indicate that there is no established framework that systematically identifies the fundamental capabilities of CTs or explains the relation among them. Furthermore, to the best of our knowledge, no study has explicitly aimed to consolidate these perspectives into a structured and validated form.

Given these gaps in literature, this research seeks to address three main questions: What is a Control Tower in a supply chain context? How can the most common types of Control Towers in the supply chain context be defined? What are the capabilities of a Control Tower in a supply chain context? By answering these questions, this study aims to contribute to the literature by providing definitions for CTs in supply chains and their main capabilities.

To achieve these objectives, this research adopts a mixed-methods approach, structured in four key phases. The first phase involves conducting a Systematic Literature Review (SLR) following the PRISMA methodology to identify, classify, and organize existing knowledge on CTs. Next phase focuses on developing two theoretical frameworks using complementary Qualitative Content Analysis (QCA) approach: one of them provide guidelines for the development of definitions that respond to the first and second research questions, and another to identify and define CTs' capabilities.

The third phase consists of capturing the impression and opinions of 21 practitioners through semi-structured interviews, allowing for an in-depth examination of industry perspectives. Finally, in the fourth phase, the study synthesizes both theoretical insights and empirical findings through Directed Content Analysis (DCA) to propose an updated definition of CTs in supply chains, in addition to allowing the refinement and validation of frameworks for the most common types of towers and their capabilities.

Regarding its relevance, this research contributes to the advancement of academic knowledge on CTs in supply chains by establishing a structured and validated conceptual foundation. Unlike previous studies that rely solely on academic literature, this research integrates empirical findings from industry practitioners, ensuring that the definitions and frameworks reflect both theoretical and real-world perspectives. Furthermore, while prior studies have described CTs in fragmented ways, this research provides a comprehensive framework that systematically defines their capabilities and classification in supply chains.

From this Introduction, this document is organized as follows. Section 2 focuses on a description of definitions and capabilities of CTs in the supply chain. Section 3 presents the research design employed in this research to reach its objectives. Section 4 discusses the study findings including the CT definitions and capabilities. Section 5 addresses the discussion of the key findings. Lastly, section 6 presents conclusions and propositions for future studies.

2. LITERATURE REVIEW

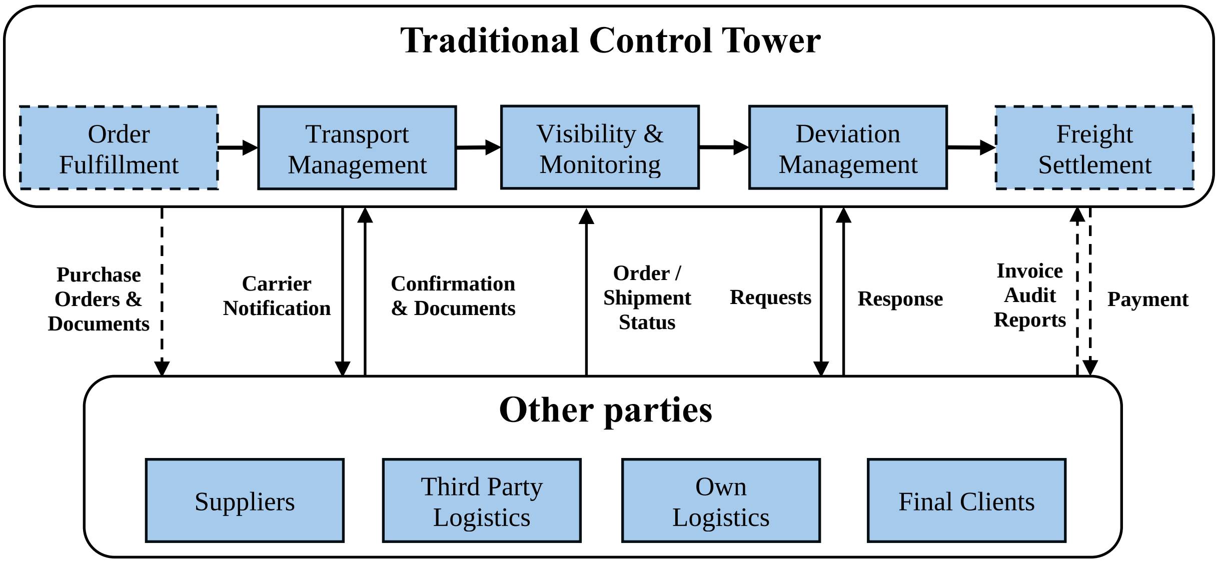
This section sheds light on the main concepts related to the objective of this research, allowing the development of an initial grasp of the matter. For a broader perspective and comprehension, see the result of SLR described in Fonseca and Guimarães (2024).

2.1. Control Towers' definitions in supply chains

The concept of a CT in the supply chain is inspired by aviation, where a controller oversees the movement of airplanes both in the air and on the ground (Vlachos, 2023). Initially, the CTs were designed with a focus on risk management to oversee the movement of shipments, aiming to reduce the insurance costs. However, quickly companies realized that more than just risk management, CTs could be used to make their operation more efficient.

Vlachos (2023) explains that CT were initially referred to as logistics CTs, with a primary focus on coordinating transportation and enhancing visibility. Over time, their capabilities have expanded to go beyond transportation management and risk reduction. Figure 1 presents the traditional view of CT functional architecture adapted from Liotine (2019), showing some transportation functions that could be incorporated in the CT scope. The dashed illustrations indicate functions that are not necessarily present in all CT.

Figure 1: Traditional view of CT functional architecture

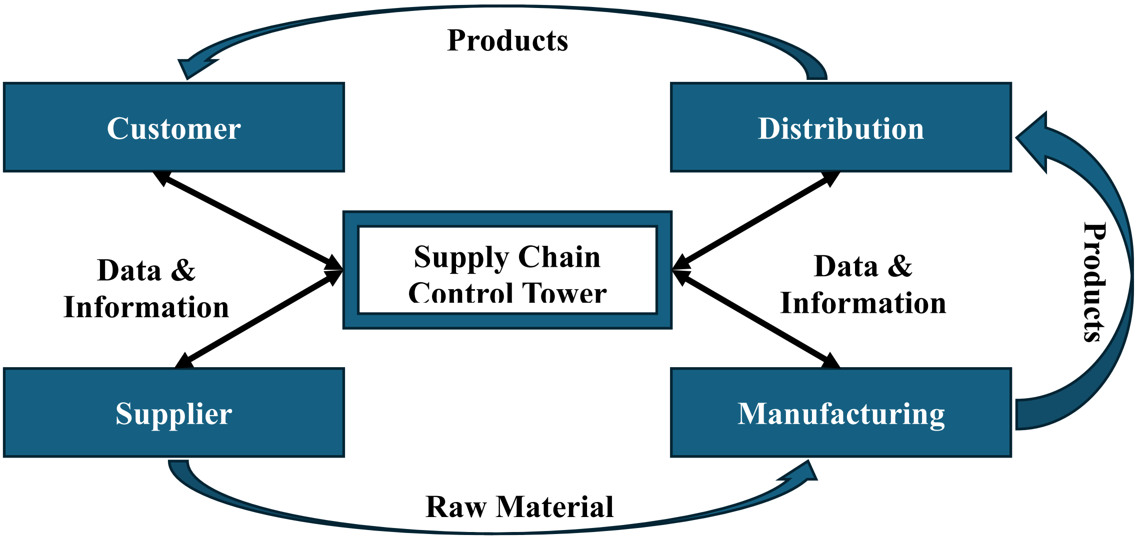


Source: Adapted from Liotine (2019).

Nowadays, CTs can foster collaboration by serving as a centralized platform for information sharing among supply chain partners (Maneegam and Udomsakdigool, 2021; Patsavellas, Kaur and Salonitis, 2021), while also optimizing costs through better operations management and automated processes (Sharabati, Al-Atrash and Dalbah, 2022; Kulkarni, 2023). They enhance agility and responsiveness by adapting to changes in demand or disruptions (Banker, 2023; Maheshwari *et al.*, 2023) and improve customer experiences with faster and more reliable service (Sharabati, Al-Atrash and Dalbah, 2022).

Figure 2 presents an updated CTs functioning, based on Vlachos' (2023) perspective, encompassing different stakeholders that exchange raw data and information with a Supply Chain Control Tower, allowing supply chain visibility and control over planning and execution in the different sections of the chain.

Figure 2: Control Tower with focus on the entire supply chain perspective



Source: Adapted from Vlachos (2023).

As a result of technological development, there is a diverse range of applications for CTs in supply chains, extending their boundaries from control specific supply chains components, such as inventory (Hasbum *et al.*, 2022), to end-to-end supply chains in diverse industries and sectors. For example, while Handfield *et al.* (2020) have proposed a CT to assist the US Government in managing the health care supply chain on a national scale in support of emergencies, while Liotine (2019) and Sharabati, Al-Atrash and Dalbah (2022) have their focus in the pharmaceutical industry.

Illustrating these different applications, Table 1 summarizes the CTs' definitions found during the SLR of the selected studies (this selection considers only the definitions that are clearly stated in the works). Although the differences in terms of labels indicate different applications, in a broader perspective, it is possible to grasp that CTs are being seen by most authors as centralized technological tools that enable visibility and control over supply chain processes.

A slightly different perspective in definitions is seen in the research of Maneegam and Udomsakdigool (2020) and Alacam and Sencer (2021), which advocate for a Transportation Control Tower (TCT). As the regular CTs, TCTs have monitoring and control capabilities but are not limited to this. Their focus is in resolving the problem of trust among third party logistics, guaranteeing neutral and reliable decision-making in order to benefit all parties.

Another distinct characteristic is provided by Maheshwari *et al.* (2023), who have chosen to highlight the three pillars of CTs: People, Process and Technology. Complementing this perspective, Sharabati, Al-Atrash and Dalbah (2022) includes the recurrent concepts already mentioned above.

Table 1: Different definitions of CT in the supply chain context adopted by authors

Authors	**Definitions**
Alacam and Sencer (2021)	TCT is an independent, neutral, and reliable third party that collects data from collaborating parties, keeps the shared data strictly confidential, and processes the data with the goal of maximizing gains for all partners.
Duarte, de Haro Moraes, and Padula (2023)	A Supply Chain Control Tower (SCCT), or a Service Control Tower (SCT), is an umbrella term for emerging solutions that bring an end-to-end view of the supply chain by acting as a central hub that integrates tools and processes to drive business outcomes. An SCCT solution is a complex set of systems and processes, and an important component of any SCCT is alert generation.
Topan *et al.* (2020); and, Gerrits, Topan, and van der Heijden (2022)	A SCT acts as a centralized hub that uses real-time data from a company's existing, integrated data management and transactional systems to integrate processes and tools across the end-to-end supply service chain and drives business outcomes.
Handfield *et al.* (2020)	A CT is defined as a centralized analytic dashboard that identifies key performance metrics for the national stockpile as a whole but that allow individuals to "drill down" to identify specific metrics related to material inventory levels, expiration dates, consumption, and other supply chain measures.
Hasbum *et al.* (2022)	A CT is categorized as the area located at the central node of the chain. Thanks to its position, its main function is to apply tools and techniques to process data and ensure the visibility of the entire supply chain. This functionality allows for a better real-time overview of the entire environment, enabling more accurate decision-making.
Hekimoglu, Kök, and Şahin (2022)	To control their spare parts inventory more efficiently, companies use data-centered monitoring and optimization models, which are referred to as control towers, to facilitate decision making processes of managers and help them to focus on important leverage points rather than the details of complex daily transactions
Kulkarni (2023)	A SCCT is traditionally defined as a connected, personalized dashboard of data, key business metrics and events across the supply chain. A supply

	chain control tower enables organizations to more fully understand, prioritize and resolve critical issues in real-time.
Liotine (2019)	In essence, a 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. It must provide fundamental capabilities to enable the levels of visibility and awareness to achieving this mission.
Maheshwari *et al.* (2023)	The SCCT is neither a physical tower nor a software product but a powerful synergy of technology, process, and skilled professionals, hence this integrated collaboration defines the true essence of an effective SCCT.
Maneegam and Udomsakdigool (2020)	TCT is a central hub to provide enhanced visibility for neutral decisions aligned with the strategic objectives of all transportation chains.
Patsavellas, Kaur and Salonitis (2021)	Conceptually, a SCCT is a shared-service center that offers real-time monitoring of the status and performance of end-to-end activities across the supply chain.
Sharabati, Al-Atrash and Dalbah (2022)	SCCT is a central system for collecting, analyzing and visualizing the progress of the SC; it alerts and initiates the corrective actions for deviations to align with organizational strategy and improve performance.
Vlachos (2023)	SCCT 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.
Wycislak (2023)	Real-time transportation visibility platforms are integrators of resources from carriers, and telematics systems into capabilities, whereas obtaining data through integration with carrier systems, direct feeds from telematics, or other devices, for example, smartphones.
Wycislak and Pourhejazy (2023)	The SCCT works as a coordination and consolidation platform to provide enhanced visibility for the efficient material flow between retailers, warehouses, factories, part manufacturers, and downstream suppliers.

Source: Author.

Summing up, apart from Topan *et al.* (2020) and Gerrits, Topan, and van der Heijden (2022), all the other definitions are unique, evidencing different perspectives and the need for proper conceptualization to clarify what really is a CT in the supply chain context. Having recognized these different perspectives of CTs, Fonseca and Guimarães (2024) have made a SLR to identify the main focus areas of CTs in the supply chains.

Table 2 presents the result of their research, connecting the focus of the CTs to the supporting authors that contributed to this identification. In a sense, it is relevant to mention that although some authors that, for example, studied CTs focused on transportation management have adopted the label TCT in their works, we do not follow this comprehension. Therefore, in this present dissertation, TCT and SCCT are not adopted as synonyms of transportation management and Supply Chain management, respectively.

Table 2: Control Towers focus and supporting authors

Focus	**Authors**
Transportation Management	Maneengam and Udomsakdigool (2020; 2021), Alacan and Sencer (2021), Vanvuchelen, Gijsbrechts and Boute (2020), Wyciślak and Pourhejazy (2023), and Wycislak (2023). Roch *et al.* (2015), and Kulkarni (2023).
Inventory and Warehouse Management	Topan *et al.* (2020), Gerrits, Topan, and van der Heijden (2022), Hekimoğlu *et al.* (2022), Ma, Hekimoglu, and Dekker (2023), Duarte, de Haro Moraes, and Padula (2023), Hasbum *et al.* (2022), Maheshwari *et al.* (2023), and Chen, Cohen, and Lee. (2024).
Supply Chain Management	Guidani, Ronzoni, and Accorsi (2024), Vlachos (2023), Sharabati, Al-Atrash and Dalbah (2022), Patsavellas, Kaur and Salonitis (2021), Banker (2021), Handfield *et al.* (2020), Liotine (2019), and Ji, Tian, and Gao (2013).

Source: Fonseca and Guimarães (2024)

The concepts and framework introduced in Section 2 provide the foundational knowledge for further understanding of what a CT in the supply chain context is. Building on this theoretical groundwork, Sections 4.1 and 4.2 will delve deeper into these concepts, combining them with practical insights gathered from industry professionals.

2.2. Control Towers' capabilities in supply chains

The current literature indicates that CT include enhanced end-to-end visibility for tracking inventory, shipments, and performance metrics (Patsavellas, Kaur and Salonitis, 2021; Sharabati, Al-Atrash and Dalbah, 2022), improved data-driven decision-making through advanced analytics and predictive models (Topan *et al.*, 2020; Maheshwari *et al.*, 2023), and effective risk mitigation by identifying potential disruptions and enabling early corrective actions (Banker, 2023; Chen, Cohen, and Lee., 2024).

Liotine (2019) asserts that visibility, analytics and execution are the essential capabilities of a CT. However, these are not unique capabilities. Table 3 summarizes the capabilities found in the SLR. In this context, it is relevant to declare that the identification process has followed the understanding that capability is seen as the combination of processes and tools to deliver a specified outcome as well as incorporated capabilities that were clearly stated by authors in their works.

Table 3: Summary of CT capabilities identified in the SLR

Author	**Capabilities**
Alacan and Sencer (2021)	Collaboration through CT solutions, Blockchain-enabled digital transportation control towers, Smart contracts for logistics.
Banker (2021)	Real-time supply chain visibility, Concurrent planning, Internal and external collaboration.
Chen, Cohen, and Lee. (2024)	Optimization of supply chain orchestration and responsiveness.
Duarte, de Haro Moraes, and Padula (2023)	Real-time monitoring, Alert generation and management, Data-driven decision support.
Gerrits, Topan, and van der Heijden (2022)	Centralized Real-Time Data Integration, Alert Management, Decision Support for Operational Planning.
Guidani, Ronzoni, and Accorsi (2024)	Real-time monitoring of Key Performance Indicators (KPIs) for facilities, Logistics efficiency optimization.
Handfield *et al.* (2020)	Centralized analytics for rapid response, Real-time inventory and logistics tracking.
Hasbum *et al.* (2022)	Central node for real-time visibility and decision-making.
Hekimoglu, Kök, and Şahin (2022)	Risk quantifiers for future stockouts, Repair expediting system.
Ji, Tian, and Gao (2013)	Visibility, Multi-layered information control system, Real-time feedback and monitoring.
Kulkarni (2023)	Live data availability, Predictive analytics, Real-time collaboration.
Liotine (2019)	Visibility, Alerting, Operational functions, Automation, Decision support, Analytics, Role transformation.
Ma, Hekimoglu, and Dekker (2023)	Real-time inventory and order progress monitoring, Optimization of replenishment and inventory management.
Maheshwari *et al.* (2023)	Warehouse management optimization, Synergy of technology and skilled professionals.
Maneegam and Udomsakdigool (2020)	Enhanced visibility for neutral decisions, Centralized collaborative planning.
Maneegam and Udomsakdigool (2021)	Coordinating routing and berthing time of barges, Centralized decision-making for cost reduction and CO2 efficiency.
Patsavellas, Kaur and Salonitis (2021)	Business to Business (B2B) integration, End-to-end mapping, Real-time monitoring, Granular visibility, Alert generation, Business analytics.
Sharabati, Al-Atrash and Dalbah (2022)	Supply chain visibility, Coordination of technology and processes, Risk management.
Topan *et al.* (2020)	Stockout prevention and intervention alerts, Decision support for operational planning.
Vanvuchelen, Gijsbrechts and Boute (2020)	Real-time shipment visualization, Replenishment decision support.

Vlachos (2023)	Cost control, Visibility, AI and Advanced Analytics, SCCT standardization for intelligent planning and execution, Transportation orchestration, and Risk mitigation
Wycislak and Pourhejazy (2023)	Supply chain orchestration, End-to-end visibility, Decision analytics, process execution, Automated decision-making.
Wycislak (2023)	Real-time transportation visibility, Resource integration.

Source: Author.

The analysis of existing literature demonstrates divergent perspectives, with different authors emphasizing distinct functionalities such as real-time monitoring, predictive analytics, orchestration, collaboration, and decision support. This fragmentation suggests that while CTs are recognized as valuable tools, their essential capabilities remain inconsistently defined and classified. Therefore, Section 4.3 presents the development of a comprehensive framework to allow a more standardized view of CT capabilities and enable a better theoretical foundation and potentially more practical implementation of CTs in supply chains.

3. RESEARCH METHODOLOGY

This study can be classified as qualitative research, using Systematic Literature Review (SLR) and Content Analysis. As a part of this research, Fonseca and Guimarães (2024) disclose in detail how the SLR was done, which is summarized in Section 3.1. Based on the SLR results and by adopting the Qualitative Content Analysis (QCA), two frameworks about CTs' concepts were developed and are presented in Sections 4.1 and 4.2. Then, Directed Content Analysis (DCA), a subtype of QCA, was applied to join both the literature review findings and data obtained from 21 interviews.

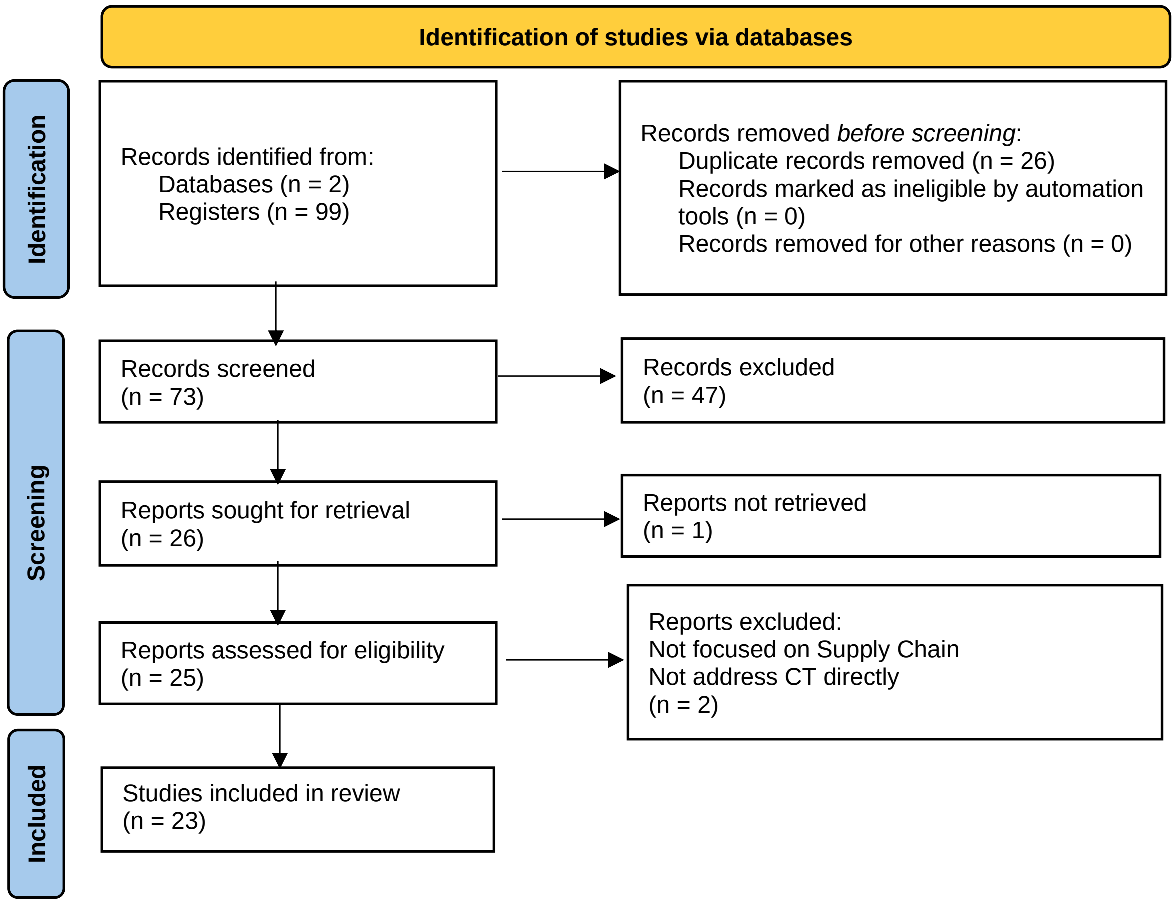
The research design, combining SLR and QCA (including DCA), was strategically chosen to address the objectives of this research. The SLR provided a comprehensive mapping of existing knowledge on CTs within the supply chain, highlighting the fragmented conceptual landscape and the absence of standardized definitions. This theoretical foundation was crucial for identifying gaps in literature.

To address these gaps, QCA was employed to categorize SLR findings and develop the proposed frameworks. \Thus, DCA allowed the validation and refinement of them, by integrating theoretical insights with empirical data gathered from industry professionals, ensuring that the concepts proposed are both academically robust and practically applicable.

3.1. Systematic Literature Review

The SLR involved a comprehensive and systematic search to locate relevant published studies that address research questions. It followed the methodology outlined by Page *et al.* (2021), with the process illustrated in Figure 3 through a PRISMA flow diagram. To ensure the inclusion of high-quality, peer-reviewed research, studies indexed in the Scopus and Web of Science databases were considered.

Figure 3: The PRISMA obtained in the systematic review process



Source: Adapted from Page *et al.* (2021).

From an initial pool of 99 articles, with 54 from Scopus and 45 from Web of Science databases, 26 duplicates were identified and removed.. The abstracts of the remaining papers were then reviewed for alignment with the study's objectives, leading to the exclusion of 47 articles. Among the 26 remaining studies, one was inaccessible. The full texts of the 25 accessible articles were thoroughly examined, revealing that one did not primarily focus on the supply chain, while another only mentioned control tower concepts indirectly. Consequently, 23 articles were selected based on the SLR process.

The review process began with a broad search using the keywords TITLE-ABS-KEY (“supply chain*" AND "control tower*") in the Scopus database. This preliminary search aimed to identify additional terms relevant to Control Towers in the supply chain, expanding the keyword set beyond the obvious. This approach led to the identification of alternative terms like Service Control Towers and Transportation Control Towers.

Based on these findings, the keyword strategy was refined to: TITLE-ABS-KEY (("digital*" OR "logistic*" OR "supply chain*" OR "service*" OR "transport*") AND "control tower*"). However, during the systematic search, a significant number of irrelevant articles related to the aviation industry (e.g., air traffic control) were retrieved. This is likely because the concept of Supply Chain Control Towers originated from aviation, where air traffic controllers manage aircraft movements in the air and on the ground (Vlachos, 2023).

To address this, exclusion terms were added to the search string, resulting in the final keywords: TITLE-ABS-KEY (("digital*" OR "logistic*" OR "supply chain*" OR "service*" OR "transport*") AND "control tower*" AND NOT ("air traffic" OR "airport")). Searches were conducted on May 6, 2024, at approximately 1:45 PM on both databases.

Articles were excluded based on language, relevance and duplication. The languages were restricted to English, Spanish and Portuguese to allow a bigger variety of studies. Relevance was assessed by reviewing the abstracts of the retrieved articles, while duplicates were manually identified and removed. Additionally, non-peer-reviewed sources such as books, reports, theses, dissertations, working papers, and conference papers were excluded from the review. There is no limitation for publication years.

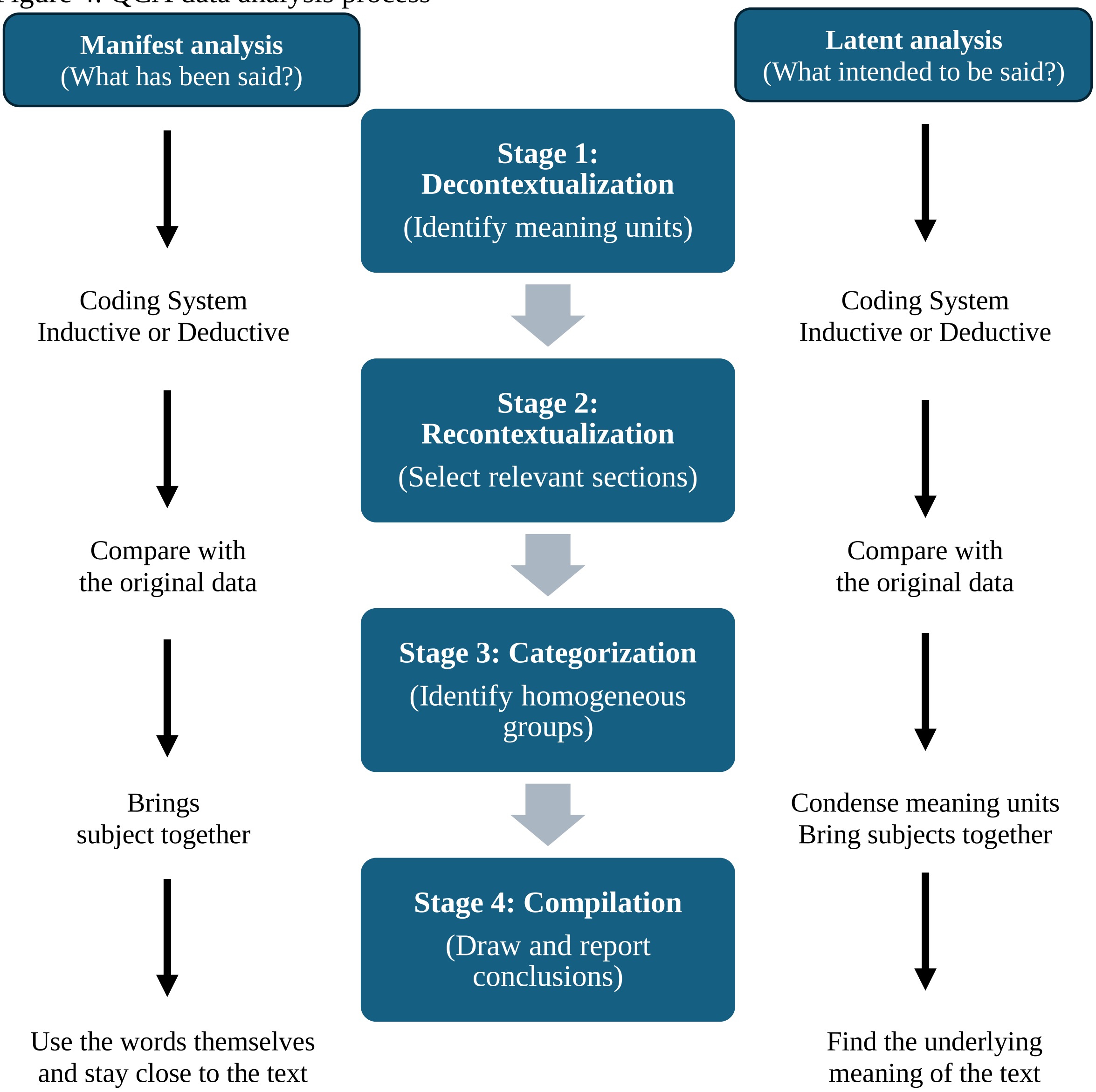
3.2. Content Analysis

Qualitative research is a methodological approach that seeks to explore and understand complex social phenomena by focusing on meanings, interpretations, and subjective experiences. (Elo and Kyngäs, 2008). This approach is particularly useful in contexts where the goal is to develop a comprehensive understanding of processes, relationships, and interactions that cannot be easily quantified.

Among them, QCA is a systematic and structured approach to analyzing textual data (Bengtsson, 2016). It is widely employed in social sciences, business, and healthcare research to classify and interpret large volumes of data in a way that reveals underlying patterns, themes, and meanings (Hsieh and Shannon, 2005).

Given its ability to provide a structured yet adaptable framework for examining qualitative data, content analysis is particularly useful for studies that aim to validate theoretical constructions while remaining open to emerging insights from empirical data (Hsieh and Shannon, 2005). Figure 4 presents data analysis methodology of QCA proposed by Bengtsson (2016), showing cases that this method allows for both manifest analysis, which focuses on explicit content, and latent analysis, which seeks to uncover implicit meanings in the data.

Figure 4: QCA data analysis process



Source: Bengtsson (2016).

Among QCA approaches, the DCA is characterized by building upon existing theories or prior research as a guiding framework for the coding and analysis of textual data (Elo and Kyngas, 2008). This method is particularly valuable when prior research and theoretical frameworks exist but require further refinement and validation through empirical data (Hsieh and Shannon, 2005). In this sense, this approach allows for the validation of existing concepts while uncovering new insights that emerge from practical experiences.

The DCA process consists of three main phases: preparation, organization, and reporting of results (Hsieh and Shannon, 2005). In the preparation phase, researchers identify initial coding categories based on existing studies and define the unit of analysis, which may range from a word or phrase to an entire theme. This step ensures the analysis remains focused on aspects most relevant to the research objectives (Elo and Kyngäs, 2008).

During the organization phase, a structured coding framework is applied to classify data into predefined categories. The analysis also allows for flexibility, as new categories or emerging concepts can be identified, ensuring that the data contribute to refining the theoretical framework when necessary (Elo and Kyngäs, 2008). This adaptability ensures the analysis respects both the predetermined structure and insights that arise from the data itself.

In the reporting phase, researchers present their findings transparently, detailing the analytical procedures, such as how categories were applied and how data are linked to existing theories. This clarity is essential for ensuring the study's credibility and reliability. The inclusion of examples or direct quotations from the analyzed data is highly recommended to enhance validity (Hsieh and Shannon, 2005; Bengtsson, 2016).

3.3. Content Analysis Application

This study applied both QCA and DCA to develop and validate frameworks related to CTs in the supply chain context. Each method was employed at different stages of the research to achieve distinct objectives as described in Sections 3.3.1 and 3.3.2.

3.3.1. Qualitative Content Analysis Application

The QCA followed the four-phase model proposed by Bengtsson (2016). In the preparation phase, data were collected from Tables 1 and 2, resulting from SLR. Relevant sections from academic articles were transcribed and organized according to the focus of each framework being developed, while only manifested analysis was adopted for CT definitions, both manifest and latent analysis were used for CT capabilities. Only one article required translation from Spanish to English.

During the decontextualization phase, meaning units were identified from the transcribed literature data, focusing on key concepts related to CT definitions and capabilities. These meaning units were coded based on recurring patterns found in the literature. The recontextualization phase involved reviewing the original texts to ensure that all relevant data were captured, while information not aligned with the research objectives was excluded.

In the categorization phase, codes were systematically grouped into subcategories and main categories, forming the foundational structure of the proposed frameworks. For each framework, examples of the process were presented using visual diagrams and tables to illustrate the logical construction of the frameworks. Finally, in the compilation phase, the results were presented using tables. This structured approach was followed in order to provide a robust theoretical foundation for subsequent empirical validation.

3.3.2. Directed Content Analysis Application

The DCA approach follows a model of three phases outlined by Hsieh and Shannon (2005), focusing on validating and refining the frameworks developed through QCA with empirical data. In the preparation phase, interviews were transcribed and translated from Portuguese to English. The unit of analysis was defined as explicit and implicit references to CT concepts and capabilities within the interview data.

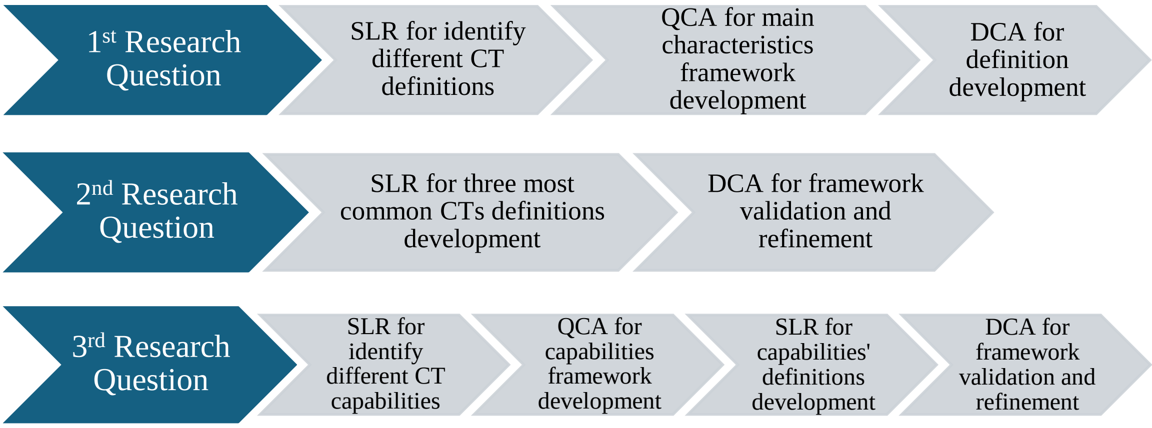
In the organization phase, initial coding categories based on the frameworks developed through QCA were used to categorize the perspectives of respondents. However, the analysis remained open to new, emergent categories that could be identified from interview data. In this context, while some participants agreed with proposed frameworks suggesting only adjustments to the frameworks, others proposed reorganizing the categories. Each suggestion was critically evaluated in the findings section.

Finally, in the reporting phase, the findings were organized and presented using tables to demonstrate how empirical data were used or not to refine theoretical frameworks. Decisions on whether to incorporate these new insights were based on the frequency of similar perspectives, their support within existing literature and relevance to study's objectives.

3.3.3. Addressing the research questions

The application of SLR, QCA and DCA was paramount in answering the three research questions of this study, allowing the joint theoretical and empirical perspectives to result in useful CT' foundational concepts. Figure 5 presents a graphic workflow of adopted methodologies allowing a better comprehension of the mix of methodologies adopted.

Figure 5: Summary of adopted methodologies



Source: Author.

For the first research question - What is a control tower in a supply chain context? - the QCA approach was used to develop a framework based on the characteristics of CT definitions identified in the literature. We reinforce, to make it clear, that the data considered in this analysis was just that presented in Table 1. As a result, a framework with five characteristics was developed and used as guidelines for DCA methodology application, which allowed joining theory and practice perspectives and finally proposed an overall definition of CTs in the supply chain context.

The second research question - How can the most common types of control towers in the supply chain context be defined? - definitions of the three most common types of CTs were developed using the framework created in the first question. Unlike the previous question, the literature reviewed was not limited to Table 1 but also included additional research identified by Fonseca and Guimarães (2024) (see Table 17). The DCA methodology was applied to refine and validate these definitions through practitioner feedback.

For the third research question - What are the capabilities of a control tower in a supply chain context? - was addressed by identifying key capabilities through the QCA process. After having identified them, based on the literature, a description of each capability was done. Further, considering these descriptions, definitions for each capability were presented. Finally, using DCA methodology the framework was validated and refined using practitioners' perspectives about it.

To ensure the credibility of the content analysis, this study employed the agreement level among interviewees as the primary measure of trustworthiness, following Bengtsson (2016). The validation of the proposed frameworks was based on the extent to which participants aligned with the concepts and definitions presented during the interviews. Additionally, the integration of theoretical insights from the SLR with empirical data collected from 21 interviews provided a form of methodological triangulation, enhancing the robustness of the findings by cross-verifying concepts.

3.4. Interview process

Primary data collection included interviews with 21 professionals from 18 different multinational and Brazilian national companies, covering a total of 11 different sectors. Appendix A presents the profile of the practitioners interviewed and Table 4 describes the distribution of the number of companies and interviewees by industry sectors.

Table 4: Respondents' industry sectors

Sectors	Number of Companies	Number of Interviewees
Chemicals	1	1
Consultancy	3	5
Cosmetics	1	1
Energy	3	2
Fertilizer	1	1
Food	3	4
Logistics Operator	2	2
Pulp and paper	1	1
Rental	1	1
Retailer	1	1
Technology	1	2

Source: Author.

The interviews had an average duration of almost one hour, with each respondent participating in a single session. The researcher transcribed the interviews, translated them from Portuguese to English, and conducted follow-ups when necessary to confirm or clarify specific points. These sessions followed a semi-structured format, covering topics such as the introduction, CT concepts, capabilities, benefits, challenges, and closing remarks.

To ensure consistency, the thematic protocol began with a brief explanation of the study's objectives, followed by questions aimed at understanding the participants' professional experience. A summary of their backgrounds is provided in Table 5 (with detailed profiles in

Appendix A). Subsequently, the developed frameworks were presented using open-ended questions to elicit feedback, while additional inquiries focused on CT concepts, benefits, challenges, and infrastructure. The full interview guide can be found in Appendix B.

Table 5: Interviewees experience information

Experience Range	Individuals	Average Experience	Standard Deviation
0-2 years	4	0.95	0.48
2-5 years	9	3.33	0.75
5-10 years	4	6.88	1.31
10+ years	4	14.50	4.80

Source: Author.

Interviewees were 21 (all men) individuals who accepted to participate in an interview to collaborate to CT' studies. The selection process followed convenience and snowballing sampling. First, 4 interviewees were recruited based on convenience sampling, using referrals from personal and professional contacts with relevant experience in the field.

Secondly, we recruited interviewees through LinkedIn. In this social media, we looked for practitioners experienced in CTs that are or were in directors, managers and coordinators positions in their companies. Invites were sent to 54 practitioners, receiving 13 acceptances. At the end of each interview, participants were asked to recommend other professionals who met the same prerequisites for participation, following the snowball sampling technique. From this, another 4 interviewees were recruited.

Although one may say that the existence of 4 individuals that have less than 2 years of experience should not be considered, these participants contributed by providing an operational and functional view of CTs, focusing on immediate and tangible aspects of their use. On the other hand, those with more experience perceive CTs as strategic components, emphasizing their broader implications for management and decision-making processes. In this sense, the inclusion of professionals with varying levels of experience has enriched the study by providing a diverse range of perspectives.

Lastly, data saturation was considered achieved when there were no new perspectives from the interviews. According to Guest *et al.* (2006), thematic saturation typically occurs within the first 12 interviews, capturing approximately 92% of the relevant themes. In this study, although key themes began to recur after the 16th interview, additional interviews were conducted to ensure comprehensive coverage and to validate the consistency of the data. By the 21st interview, the collected data demonstrated an overlap, indicating that saturation had been achieved.

4. FINDINGS

This section presents the results of the research, focusing on defining CTs in the supply chain context, classifying the most common types of CTs, and identifying their key capabilities. These accomplishments are presented in Sections 4.1, 4.2, and 4.3, respectively.

4.1. Control Tower in supply chains definition

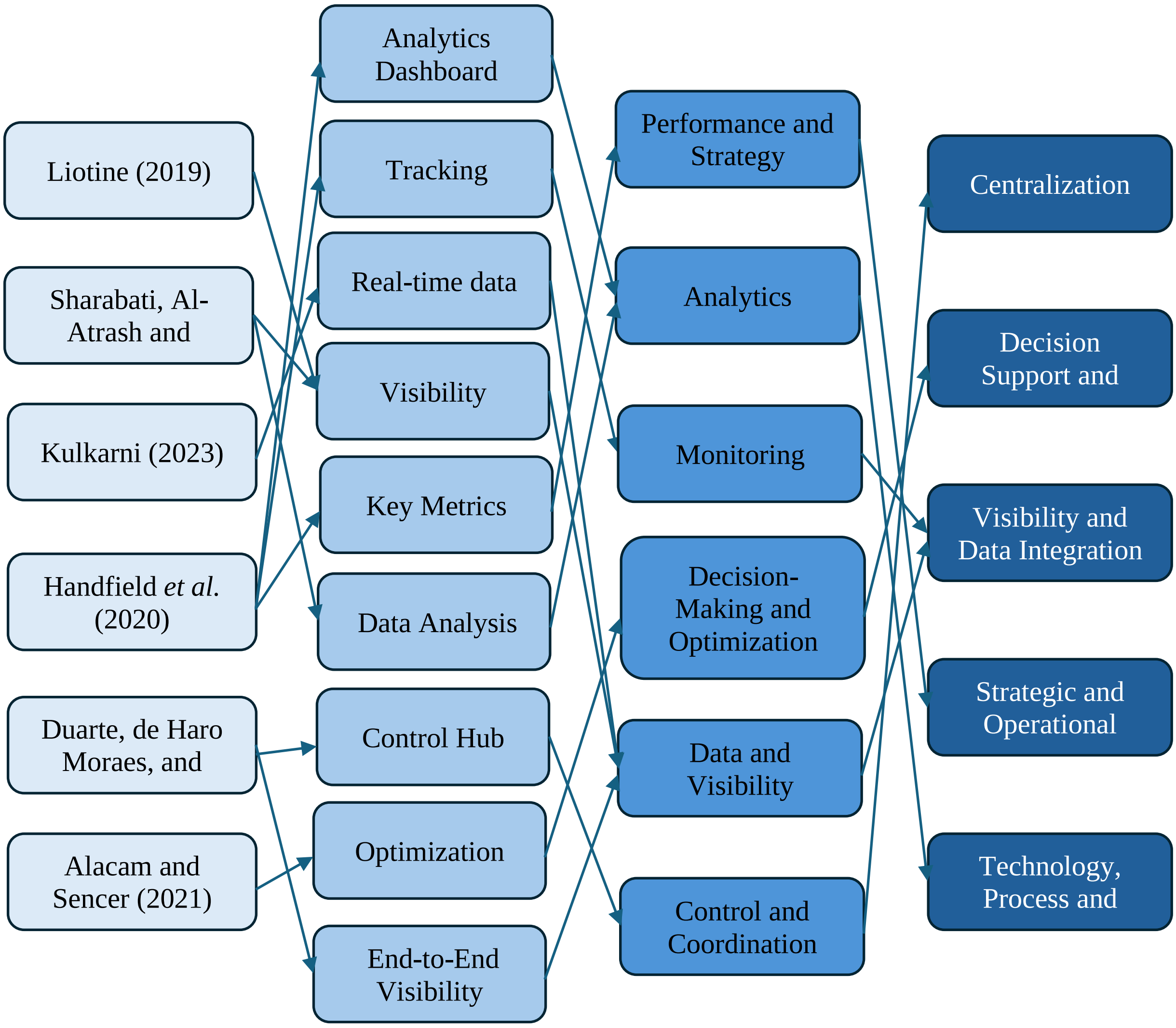
This section answers the first research question. Following the methodology described in Section 3.3.3, the QCA approach resulted in a framework of main characteristics of the CT definitions composed by Centralization, Visibility and Data Integration, Decision Support and Alerting, Technology, Processes and People and Strategic and Operational Impact. In sequence, these categories provided support to incorporate empirical feedback, using the DCA approach, and resulted in the definition described in Section 4.1.2.

4.1.1. Establishing the conceptual framework for Control Tower definitions

A diverse range of definitions was considered, each emphasizing different aspects of CTs. Some scholars, such as Duarte, de Haro Moraes, and Padula (2023), describe CTs as centralized hubs that integrate tools and processes to drive business outcomes, while others, like Kulkarni (2023), highlight their role as real-time data dashboards that enable organizations to prioritize and resolve critical issues. Moreover, Liotine (2019) positions CTs as centers of excellence that coordinate complex supply chain networks.

To systematically develop a structured framework for defining CTs in the supply chain context, this study has used QCA methodology in four steps, as proposed by Bengtsson (2016). Figure 6 provides examples of the categorizing process. In the first step, we systematically reviewed sixteen academic papers to identify explicit meanings within CT definitions. We reinforce that the other seven articles present in the SLR did not clearly state their definitions, so they were not considered in the analysis provided in this section.

Figure 6: Categorizing process example following QCA process



Source: Author.

In sequence, each definition was broken down into meaning units, representing core elements of how CTs are conceptualized. These meaning units were then assigned to initial codes that captured key themes, such as "Control Hub," "Real-time data," "Optimization," and "Key Metrics." Each meaning unit was depicted in one or more codes.

Next, we re-examined the extracted meaning units to ensure that all relevant aspects of CT definitions were captured in alignment with the research objectives. During this process, we compared our coded meaning units with the original texts to confirm their contextual relevance and removed any information that did not directly contribute to the definition of CTs.

Following the structured content analysis approach, we grouped related codes into sub-categories, which represented common functional aspects of CTs. These subcategories were then mapped to five conceptual categories that represent the main characteristics of the CTs stated in their definitions by the authors evidenced in the SLR. Finally, in the compilation step, we synthesized the findings of the five final categories and found definitions for them based on literature. Table 6 presents the conceptual framework for characteristics of CT definitions.

Table 6: Conceptual framework for characteristics of CT definitions

Category	**Definition**	**Supporting papers**
Centralization	CTs are described as a hub, command center, coordination platform, or centralized system that integrates various supply chain elements.	Duarte, de Haro Moraes, and Padula (2023); Topan *et al.* (2020); Hasbum *et al.* (2022); Vlachos (2023); Wycislak and Pourhejazy (2023)
Visibility and Data Integration	CTs enable real-time monitoring, data collection, analysis, and visualization to ensure comprehensive supply chain visibility.	Handfield *et al.* (2020); Kulkarni (2023); Patsavellas, Kaur and Salonitis (2021); Sharabati, Al-Atrash and Dalbah (2022); Wycislak (2023)
Decision Support and Alerting	CTs generate alerts, support decision-making, and assist in proactive resolution of disruptions.	"Hekimoglu, Kök, and Şahin (2022); Sharabati, Al-Atrash and Dalbah (2022)
Technology, Processes and People	CTs rely on technological systems, predictive analytics, integration with organizational processes and people to function effectively.	Liotine (2019); Maheshwari *et al.* (2023); Sharabati, Al-Atrash and Dalbah (2022)
Strategic and Operational Impact	CTs drive efficiency, collaboration, problem-solving, and business value creation.	Alacam and Sencer (2021); Wycislak (2023); Vlachos (2023)

Source: Author.

4.1.2. Control Tower concept definition development

With the conceptual framework of main characteristics of CT definitions established, the next step is to develop the definition of CT in the supply chain using deductive DCA methodology, following the structured methodology proposed by Hsieh and Shannon (2005). This method allowed the integration of empirical insights, ensuring that the final definition reflects both academic theory and industry practice.

The process began in the preparation phase, when the unit of analysis was defined as the explicit and implicit meaning in CTs definitions from practitioner responses and the data sources were 16 academic papers definitions (See Table 1) and 19 industry professionals (See Appendix C for responses to the question “How do you define the concept of CTs in the supply chain?”).

Next, in the organizing phase, the initial conceptual framework served as a coding structure, where data were categorized into one of the five predefined themes or in a sixth one for concepts that did not fit the framework, ensuring a structured approach to analyzing interview data. Table 7 presents the categorization process example, mapping theoretical definitions and practitioners' responses to the predefined categories.

Table 7: Categorization process example

Condensed Meaning Unit	**Centralization**	**Visibility and Data Integration**	**Decision Support and Alerting**	**Technology Processes and People**	**Strategic and Operational Impact**	**Other**
Central hub providing enhanced visibility for neutral and strategic decision-making (Maneegam and Udomsakdigool, 2020)	Central hub	providing enhanced visibility	strategic decision-making			Neutral decision-making
Centralized real-time operational information system (Respondent 16)	Centralized	operational real-time		information system		

Source: Author.

Resulting from this analysis for all academic and practical definitions, it was possible to verify which categories have been more frequently mentioned in the definitions and conclude that the framework developed is useful since no other categories have appeared with relevant contributions. Table 8 summarizes the occurrences in each category.

Table 8: Concepts mentioned in the categorization by each source

Source	**Centralization**	**Visibility and Data Integration**	**Decision Support and Alerting**	**Technology, Processes and People**	**Strategic and Operational Impact**	**Other**
Academic	10	13	10	10	6	2
Practitioner	6	13	11	10	7	0

Source: Author.

Overall, the data shows that Visibility and Data Integration is the most frequently mentioned category by both groups, with 13 occurrences in academic definitions and 13 in professional definitions. This indicates a strong consensus on the essential role of CTs in real-time monitoring, data consolidation, and providing a unified view of the supply chain. The alignment between the two groups reinforces that visibility is a core pillar of these systems, crucial for both academic understanding and practical implementation.

The second most cited category is Decision Support and Alerts, mentioned 11 times by professionals and 10 times by academics. This highlights the importance of CTs not just as monitoring tools but also as decision-support systems, particularly through alert generation and predictive analytics to anticipate issues and enhance operational responses. The slightly higher emphasis from professionals suggests that, in practice, these functionalities are particularly valued for quick and effective decision-making in daily operations.

The Technology, Processes and People category appears with 10 mentions in both groups, emphasizing the universal recognition of the need for system integration, automation, and analytical intelligence to ensure CTs function efficiently. This alignment suggests that, regardless of perspective, CTs are seen as reliant on advanced technological solutions to fulfill their role.

In contrast, Centralization shows a more significant difference between the groups. Academics mention this concept 10 times, while professionals cite it only 6 times. This suggests that, in theory, CTs the centralization perspective is clearly recognized as an essential component rather than in practice.

Strategic and Operational Impact is the least mentioned category, appearing 6 times in academic literature and 7 times among professionals. This suggests that while CTs are recognized as valuable tools for improving supply chain efficiency and management, their strategic and operational impact is not a primary focus in definitions. Academics and professionals alike seem to prioritize describing the technical and operational capabilities of CTs, with strategic benefits often assumed rather than explicitly discussed.

Therefore, the findings indicate that the three core concepts mentioned in the definitions of CTs are "Visibility and Data Integration", "Decision Support and Alerts," and "Technology, Processes, and People" widely acknowledged in both theory and practice. However, differences arise regarding centralization, which is more emphasized in academic literature, and strategic impact, which is the least discussed by both groups.

Finally, in the reporting phase, resulting from an in-depth analysis of both academic literature and industry and using the above-mentioned analysis as guidelines to find robust support in the academic literature, the following definition for a CT in the supply chain context is proposed:

"**A control tower is a centralized system that provides end-to-end visibility and control in real-time by integrating people, processes, and technology and supporting decision-making to enable supply chain operational efficiency improvement**."

In the proposed definition, the term "centralized system" reflects the academic consensus that CTs function as hubs that consolidate information flows and coordinate actions across different supply chain entities (Duarte, de Haro Moraes, and Padula, 2023, Topan *et al.*, 2020, Gerrits, Topan, and van der Heijden, 2022, Hasbum *et al.*, 2022, Sharabati, Al-Atrash and Dalbah, 2022). Authors such as Handfield *et al.* (2020) and Vlachos (2023) define CTs as centralized systems that facilitate operational oversight and governance, while industry professionals highlight their role in orchestrating supply chain processes from a single point of command.

The phrase "end-to-end visibility and control" was incorporated to align with the recurring theme found in literature and practice, emphasizing the ability of CTs to monitor and manage supply chain operations. Academic sources, such as Sharabati, Al-Atrash and Dalbah (2022) and Patsavellas, Kaur and Salonitis (2021), highlight the critical role of CTs in offering a comprehensive view of supply chain activities, enabling better planning and execution. Practical definitions reinforce this concept by frequently referencing the importance of having complete traceability and monitoring across different operational areas.

Additionally, we highlight that the word "control" has emerged as the most frequently cited keyword across both academic and practical sources, emphasizing the fundamental function of a CT in overseeing operations. The inclusion of "control" acknowledges the dual role of CTs in both providing oversight and enabling proactive interventions (Handfield *et al.*, 2019; Patsavellas, Kaur and Salonitis, 2021).

The expression "real-time" was selected based on its frequent occurrence in interview responses and practical definitions, where CTs are described as systems that provide uninterrupted monitoring and tracking. Respondents frequently referred to the need for continuous and in real-time data to respond quickly to disruptions and deviations, which aligns with the literature's emphasis on the necessity of timely and accurate information for effective decision-making, as discussed by Hasbum *et al.* (2022) and Kulkarni (2023).

The phrase "by integrating organizations, processes, and technology" was included to reflect the CT's proper operation based on its three pillars – people, process and technology –

synergy (Maheshwari *et al.*, 2023). Academic sources, such as Vlachos (2023) and Sharabati, Al-Atrash and Dalbah (2022), emphasize the importance of integrating different supply chain functions, stakeholders, and systems to enable efficient operations, which was also echoed by interviewees who described the CT as an "integrator hub" that connects various entities through technology.

“Supporting decision-making” was included to capture the high frequency of occurrences, which are consistently emphasized in both theoretical and practical definitions. Academic sources such as Hekimoglu, Kök, and Şahin (2022) and Maheshwari *et al.* (2023) describe CTs as analytical platforms that enhance decision-making through data insights, while interviewees highlighted their practical role in enabling better operational responses based on data-driven insights.

Finally, the inclusion of “operational efficiency improvement” reflects the widely acknowledged value of CTs in improving supply chain performance by optimizing resources and processes. Authors such as Wycislak and Pourhejazy (2023) and Topan *et al.* (2020) mention the efficiency improvements enabled by CTs, and industry practitioners consistently emphasized their role in reducing costs, improving service levels, and increasing overall operational effectiveness.

Despite the significant value attributed to the strategic and long-term planning focus in academic definitions, we intentionally chose not to incorporate this aspect explicitly in our definition. Academic sources often describe CTs as tools for overarching supply chain optimization and alignment with long-term strategic goals (e.g., Liotine, 2019; Vlachos, 2023; Sharabati, Al-Atrash and Dalbah, 2022). However, our analysis of industry perspectives revealed a more immediate focus on operational efficiency, real-time responsiveness, and problem-solving, which were prioritized as key practical needs.

It is important to acknowledge that, inevitably, a CT will serve as a foundation for strategic-level decision-making. However, we understand that this is not an immediate outcome. Rather, it is a result that evolves over time as the CT matures, accumulates historical data, and enhances its analytical capabilities. Since the system continuously improves and adapts to organizational needs, it gradually transitions from being purely operational to one that supports strategic planning and long-term supply chain optimization.

Additionally, elements such as neutrality and confidentiality, which are emphasized by authors like Alacam and Sencer (2021) and Maneegam and Udomsakdigool (2020), were excluded from the definition. These aspects are often associated with third-party logistics providers but do not necessarily align with the way CTs are implemented internally within organizations. Similarly, the adaptability and customization of CTs, frequently mentioned in practitioners' definitions, were not explicitly included to keep the definition concise and universally applicable across different industries and supply chain structures.

4.2. Conceptual definitions of the most common types of CTs in the supply chain context

This section demonstrates the development and reaches refined and validated definitions for the most common types of CTs in supply chains. With this purpose, Section 4.2.1 illustrates the development of initial definitions of them and Section 4.2.2 their refinement and validation process.

4.2.1. Defining the most common types of CTs

The basis for this development is the study of Fonseca and Guimarães (2024). The authors have done a SLR to identify the most common types of CTs in the supply chain context. Their study resulted in the identification of the three main focus areas. Table 2, presented in Section 2.1, provides information over them as well as the other authors that have supported the identification of the focus areas. From now on, the analysis focuses on five characteristics that underpin the definitions of CTs: Centralization, Visibility and Data Integration, Decision Support and Alerting, Technology, Processes and People, and Strategic and Operational Impact.

Relating to centralization, Maneengam and Udomsakdigool (2020) describe transportation management CTs as neutral, independent digital platforms that consolidate data from shippers, carriers, and ports to ensure transparent, efficient planning and fair profit-sharing. Similarly, Wycislak (2023) emphasizes the implementation of CTs for centralized operations, enabling real-time data integration and streamlined logistics management.

Moreover, real-time visibility and data integration are essential functions of these platforms. Vanvuchelen, Gijsbrechts, and Boute (2020) highlight the role of CTs in visualizing shipments and supporting replenishment decisions through real-time analytics. Wycislak & Pourhejazy (2023) further stress that transportation CTs integrate data from IoT devices, telematics, GPS systems, and regulatory bodies, providing end-to-end visibility and facilitating the efficient flow of materials across supply chains.

Beyond visibility, CTs enhance coordination and decision support through predictive analytics and automated alert systems. Kulkarni (2023) notes that these CTs are dynamic platforms that capture live data, predict disruptions, and suggest corrective actions, distinguishing them from traditional, static dashboards. Maneengam and Udomsakdigool (2021) explain how CTs coordinate green ship routing and scheduling, reducing operational costs while optimizing performance. Additionally, Alacan and Sencer (2021) explore how blockchain-based CTs use smart contracts to automate shipment workflows, ensuring transparent, real-time decision execution.

The effectiveness of CTs also relies on integrating advanced technologies with business processes and human expertise. Wycislak & Pourhejazy (2023) describe how IoT, AI, and cloud platforms support centralized planning and control, while Alacan and Sencer (2021) highlight the role of blockchain in fostering trustless collaboration by eliminating intermediaries and ensuring data privacy, a possible solution for the problem of competition instead of collaboration identified by Wyscilack (2023) in the shipment industry.

Strategically, CTs can drive business outcomes such as efficiency, sustainability, and resilience in transportation management. Maneengam and Udomsakdigool (2020) emphasize how centralized collaborative planning reduces costs and CO_2 emissions. Horizontal collaboration, as discussed by Alacan and Sencer (2021), allows carriers to pool resources, improve service quality, and compete for larger contracts, fostering long-term business value. Kulkarni (2023) adds that the proactive responses enabled by CTs enhance supply chain resilience, enabling organizations to swiftly adapt to disruptions and optimize performance.

When the focus is on inventory and warehousing, visibility will be provided, for instance, over its inventory levels, in-transit goods and order status (Maheshwari *et al.*, 2023). Complementing these perspectives, Topan *et al.* (2020) emphasize the importance of real-time stock monitoring to prevent shortages and Hekimoğlu *et al.* (2022) discuss the role of IoT sensors in enhancing warehouse tracking accuracy.

Coordination also plays a role in these CTs, focusing on system integration within companies and collaboration across warehouse networks. Ma, Hekimoglu, and Dekker (2023) emphasize strategies for dynamic replenishment through integrated systems, ensuring optimal stock levels and reduced lead time variance. Duarte, de Haro Moraes, and Padula (2023) further discuss the role of collaborative networks in optimizing warehouse performance by streamlining operations between suppliers and distribution centers.

In terms of decision support, CTs leverage predictive tools and alert systems to enhance operational control and responsiveness. Maheshwari *et al.* (2023) discuss how analytics support scenario development for realigning inventories and achieving operational goals while addressing challenges like data gaps and resource constraints. Gerrits, Topan, and van der Heijden (2022) explain how alert-based systems detect stock deviations, enabling timely corrective actions to minimize disruptions. Chen, Cohen, and Lee (2024) present predictive analytics applications for proactive inventory replenishment planning.

The strength of these CTs is rooted in their capacity to merge new technologies with business workflows and human insights. Hekimoğlu *et al.* (2022) illustrate how data-driven monitoring and optimization frameworks streamline decision-making, guiding managers toward high-impact areas instead of routine transactional details. Maheshwari *et al.* (2023) underscore the integrated approach of technology, processes, and skilled personnel in stabilizing inventory fluctuations and mitigating supply chain interruptions.

From a strategic perspective, CTs significantly enhance operational outcomes by adjusting stock precision, shortening lead times, and avoiding both stockouts and overstock issues. Ma, Hekimoglu, and Dekker (2023) highlight the pivotal role of dynamic replenishment strategies in minimizing lead time variability, while Gerrits, Topan, and van der Heijden (2022) stress the necessity of timely interventions to preempt inventory shortfalls. In this sense, CTs in inventory and warehousing management support supply chain agility and effectiveness.

Unlike transportation and inventory management CTs, the ones with a focus on supply chain management allow visibility and control over end-to-end supply chain activities. A key feature of these CTs is their ability to centralize and coordinate different supply chain functions, ensuring smooth and efficient operations. Vlachos (2023) explains how CTs merge procurement, manufacturing, and logistics activities to enhance supply chain effectiveness, while Ji, Tian, and Gao (2013) emphasize the significance of aligning procurement with logistics to minimize inefficiencies and reduce bottlenecks. This coordinated approach promotes stronger collaboration and better data sharing among stakeholders, improving supply chain transparency (Handfield *et al.*, 2020).

In this context, Handfield *et al.* (2020) and Sharabati, Al-Atrash, and Dalbah (2022) highlight CTs' essential role in offering real-time visibility across all supply chain tiers, allowing quick reactions to disruptions and bolstering overall resilience. Additionally, Banker (2021) highlights CTs solutions that provide real-time visibility to supply chain risks, continuously monitor diverse risk factors and link these risks to a map of the customer's end-to-end, multi-tier supply chain, ensuring effective monitoring and intervention.

CTs focused on the end-to-end supply chain significantly contribute to both strategic and operational decision-making processes. Patsavellas, Kaur, and Salonitis (2021) point out the value of scenario planning tools integrated within CTs, which allow managers to anticipate risks and shape effective mitigation plans. Guidani, Ronzoni, and Accorsi (2024) demonstrate how CTs enhance proactive risk management and support well-informed decisions, thereby reinforcing supply chain robustness.

Like the other types of CTs, people, processes and technology play a significant role in the supply chain CT. In this sense, Vlachos (2023) illustrates how CTs utilize IoT, big data, and cloud technologies to facilitate intelligent planning and real-time execution. Sharabati *et al.* (2022) describe CTs as centralized command centers that gather and analyze data from various sources, driving improved collaboration and fostering innovative solutions throughout the supply chain.

Finally, from a strategic point, these CTs can deliver substantial business benefits as they are the most capable of understanding the trade-offs and consequences of a single decision in the whole chain. Therefore, Ji, Tian, and Gao (2013) highlight how coordinated supply chain processes help reduce inefficiencies, while Patsavellas, Kaur, and Salonitis (2021) showcase how CTs empower proactive measures to prevent potential disruptions as well as contribute for overall operational improvement.

Table 9 presents the final definitions based on the above-mentioned CT characteristics. It is important to note that although authors have recognized the application of the category "Technology, people and process" in each type of CT, it is decided not to mention that explicitly as have already been done in Section 4.1. This is because it is understood that it is already embedded in the definition and the possible add of them could overlap other presented information that effectively characterizes each type of CT.

Table 9: Summary of Control Towers focus and definitions

Focus	**Common Definition**
Transportation Management	A centralized digital platform that enhances visibility (Vanvuchelen, Gijsbrechts and Boute, 2020; Wycislak, 2023), coordination (Maneengam and Udomsakdigool, 2020; Alacan and Sencer, 2021), and decision support (Maneengam and Udomsakdigool, 2021) of transportation activities within a supply chain. It integrates real-time data from various stakeholders, including shippers, carriers (Wycislak, 2023), and regulatory bodies (Wyciślak and Pourhejazy, 2023), to provide a holistic view of the entire transportation process.
Inventory and Warehouse Management	A centralized digital hub specifically focused on providing real-time visibility (Topan *et al.*, 2020; Hekimoğlu *et al.*, 2022), coordination (Ma, Hekimoglu, and Dekker, 2023; Duarte, de Haro Moraes, and Padula, 2023), and decision support (Maheshwari *et al.*, 2023; Gerrits, Topan, and van der Heijden, 2022; Chen, Cohen, and Lee., 2024) over inventory and warehouse operations. It integrates data from various sources such as inventory levels, warehouse locations, and order statuses to optimize stock accuracy (Maheshwari *et al.*, 2023), reduce lead times (Ma, Hekimoglu, and Dekker, 2023), and prevent stock outs or overstock situations (Gerrits, Topan, and van der Heijden, 2022).
Supply Chain Management	A centralized digital hub that provides end-to-end visibility (Handfield *et al.*, 2020; Sharabati, Al-Atrash and Dalbah, 2022), coordination (Vlachos, 2023; Ji, Tian, and Gao, 2013), and decision support (Patsavellas, Kaur and Salonitis, 2021; Guidani, Ronzoni, and Accorsi, 2024) over the entire supply chain, encompassing transportation, inventory, manufacturing, procurement, and logistics (Ji, Tian, and Gao 2013; Vlachos, 2023). It integrates data from these various sources to enhance decision-making and ensure end-to-end transparency (Handfield *et al.*, 2020).

Source: Author.

4.2.2. Validating and refining CT' definitions framework based on interviews data

The analysis developed in this section is based on the answers described in Appendix E for the questions of fourth phase of interview script (See Appendix B). Based on the interview's responses for questions 4.1, "Based on your experience, do these three types of CTs correspond to what currently exists in the supply chain?", it was possible to reach the level agreement by having 15 (75%) practitioners that agreed with the presented definitions (Respondents 1, 2, 4, 5, 7, 8, 9, 10, 11, 12, 15, 16, 17, 19, 21), 5 (20%) practitioners that have partially agreed with the presented definitions (Respondents 3, 6, 13, and 14) and one (5%) practitioner that has partially disagreed with the presented definitions (Respondent 20).

Although it was possible to validate the framework, the comments and suggestions made in interviews indicates that there is room for refinement in the definitions, as new concepts arose from interviews (Elo and Kyngäs, 2008). Moreover, to allow an even more complete analysis, the answers for Question 3.1, “How do you use control towers in your daily operations?” will be also considered to contribute to the second objective of the present research.

Hence, following the DCA process, the observations related to the framework were coded considering four categories. Three categories suggested by Fonseca and Guimarães (2024) and a fourth different group that did not fit the framework. Table 10 presents responses related to CT with a focus on transportation management.

Among them, respondent 12 said that deviation management is not clearly stated in the current definition. Kulkarni (2023), who emphasizes that CT constantly monitors ongoing activities and recommends corrective interventions, provide evidence in support to this suggestion. Respondent 8 further supports this by stating that CTs with focus on transportation must identify key offenders and allow for proactive corrections, reinforcing the necessity of real-time deviation tracking and intervention. Since its empirical and theoretical relevance, it was considered to refine the definition.

Table 10: Responses related to transportation management CTs

Respondent	**Response**
Respondent 8	The definition is summarized. Mentions that the transportation control tower identifies key offenders and allows proactive corrective actions.
Respondent 9	Mentioned that it is difficult for the control tower to be effectively real-time due to costs.
Respondent 12	I believe that the essence of the control tower is deviation management, and this is not clearly stated in the definitions.
Respondent 13	Mentioned that the transportation control tower should provide data to assist in better truck fleet planning.
Respondent 14	In the transportation control tower, I would mention the relevance of the people working in the tower to make it function.
Respondent 17	I would add continuous improvement to the definition.
Respondent 21	Planning and routing should also be mentioned within the transportation control tower.

Source: Author.

Respondent 9 points out the difficulties in achieving real-time operations due to cost constraints. Corroborating, Wycislak (2023) acknowledges that while real-time visibility is fundamental, it requires significant investment in IoT, telematics, and cloud computing infrastructure. On the other hand, Vanvuchelen, Gijsbrechts and Boute (2020) asserts that real-time is necessary to foster smooth freight routing across the supply chain network, and Alacan and Sencer (2021) highlights that it is necessary to collaborate among parties. In this context, real-time information exchange is seen as foundational to allow timely and corrective responses (Kulkarni, 2023), indicating that without it there is no CT, but rather another control system. So, this appointment was not further used.

The role of planning and routing within the TCT is emphasized by Respondents 13 and 21. This aligns with the study of Maneegam and Udomsakdigool (2021), who discuss how CTs support routing and scheduling optimization for carriers, ensuring efficiency and cost reduction. Additionally, Vanvuchelen, Gijsbrechts and Boute (2020) highlight that CTs can leverage analytics to support replenishment and shipment decisions, which inherently involve route optimization and planning. Furthermore, many CTs with focus in transportation management described in the interviews have planning, routing and scheduling capabilities, which reinforce the validity of adding these concepts to the definition. Hence, it was used to refine the definition.

Respondent 14 highlights that the people working in the CT play a crucial role in its functioning. This study has already repeatedly mentioned the relevance of people, processes and technology for CTs (as in Patsavellas, Kaur and Salonitis, 2021), to the point of including them in the proposed general definition of CTs (see Section 4.1). However, in the specific definitions of each type of CT, we seek a concise and direct description of what is paramount for that specific CT. Therefore, this suggestion was not used to refine the definition.

Another refinement suggested by Respondent 17 is the inclusion of continuous improvement as a key function of CTs with a focus on transport. In this context, Kulkarni (2023) asserts that CT connects data from different systems, helping to understand where improvements are needed, and how to make them. Moreover, providing a real example of that, Respondent 11 mentions that there are process improvement and cost audit centers linked to the CT, using their data to optimize operation. Hence, due to its empirical and theoretical validity, it was incorporated in the updated definition.

Based on the new perspectives, the updated definition for CTs with focus on transport management is: A centralized digital hub designed to enhance visibility (Vanvuchelen, Gijsbrechts and Boute, 2020), coordination (Maneengam and Udomsakdigool, 2020; Alacan and Sencer, 2021), and decision support (Maneengam and Udomsakdigool, 2021) of transportation activities, enabling deviation management and continuous process improvement. It integrates real-time data from various stakeholders, including shippers, carriers (Wycislak, 2023), and regulatory bodies (Wyciślak and Pourhejazy, 2023), to provide a holistic view of the entire transportation process. It can encompass planning, routing, execution and scheduling (Maneengam and Udomsakdigool, 2021).

Table 11 presents responses related to CT with a focus on inventory and warehousing management. Beginning their analysis, Respondent 2 felt that the definition provided seemed to be aimed at a cross-chain inventory CT. However, the definition is intended to be broad enough to encompass both cross-chain and traditional warehousing. While some CTs operate across multiple warehouses, like the example provided by Respondent 9 who developed a CT in a logistic operator within multiple warehouses, others function within a single organization to manage internal stock levels efficiently (Duarte, de Haro Moraes, and Padula, 2023). Given that both applications exist in practice, the overall definition was checked to guarantee flexibility without favoring one over the other.

Table 11: Responses related to inventory and warehousing management CTs

Respondent	**Response**
Respondent 2	The definition of the Inventory Control Tower seems to be aimed at a cross-chain inventory control tower.
Respondent 8	The definition is summarized. In the inventory control tower, I would emphasize the capacity for space optimization.
Respondent 9	Mentioned that it is difficult for the control tower to be effectively real-time due to costs.
Respondent 12	I believe that the essence of the control tower is deviation management, and this is not clearly stated in the definitions.
Respondent 17	I would add continuous improvement to the definition.

Source: Author.

Respondent 8 emphasizes the importance of space optimization in CTs. Maheshwari *et al.* (2023) support this perspective by highlighting that CTs enable efficient warehouse and inventory allocation by integrating real-time data and advanced analytics. The ability to optimize warehouse space, balance stock levels, and reduce storage inefficiencies is a relevant function of CTs with focus on inventory and warehouse management, making it a relevant addition to the definition.

As happened with CTs focused on transportation management, Respondent 12 also suggests refinements related to including deviation management in the definition. Providing support to this view Topan *et al.* (2020) points out that CTs use automated alerts to address issues such as stockouts, excess inventory, or supply chain disruptions. Therefore, as the role of deviation management in inventory control is fundamental when unexpected fluctuations in demand or supply require rapid interventions, this suggestion was used in the refinement.

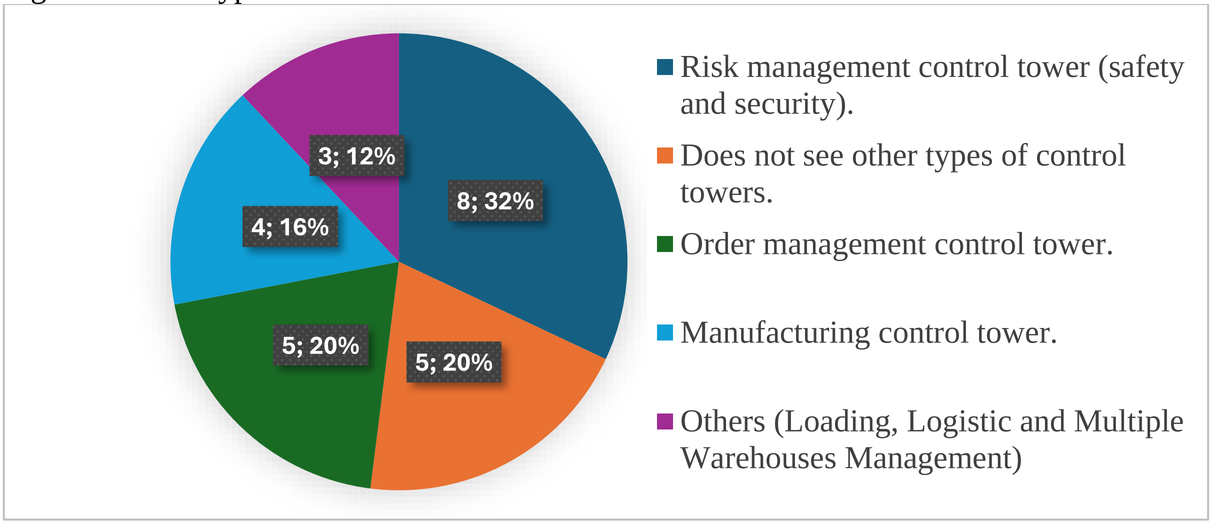
Respondent 9 raises again concerns about the feasibility of real-time operations due to cost constraints. However, the authors that support the inventory CT definition did not mention this worry. In truth, they go the other way, stating real-time data as a key aspect in differentiating traditional control systems from CTs (Duarte, de Haro Moraes, and Padula, 2023). As pointed out by Ma, Hekimoglu, and Dekker (2023), real-time visibility is essential for accurate order tracking, replenishment planning, and demand forecasting, which justifies its inclusion in the definition.

Respondent 17 suggests that continuous improvement should be explicitly included in the definition. This perspective is well-supported by Duarte, de Haro Moraes, and Padula (2023), who describe how CTs integrate analytics and historical data to refine inventory strategies over time. Additionally, Hekimoğlu *et al.* (2022) emphasize that CTs can help identify process inefficiencies and implement iterative improvements to reduce costs and enhance stock accuracy, reinforcing the need to incorporate it into the updated definition.

Based on the new perspectives, the updated definition for CTs with focus on inventory and warehouse management is: A centralized digital hub designed to enhance visibility (Topan *et al.*, 2020; Hekimoğlu *et al.*, 2022), coordination (Ma, Hekimoglu, and Dekker, 2023; Duarte, de Haro Moraes, and Padula, 2023), and decision support (Maheshwari *et al.*, 2023; Gerrits, Topan, and van der Heijden, 2022; Chen, Cohen, and Lee., 2024) over inventory and warehouse operations. It integrates real-time data such as inventory levels, warehouse locations, and order statuses from various sources to allow deviation management (Topan *et al.*, 2020), optimize stock accuracy and space (Maheshwari *et al.*, 2023), reduce lead times (Ma, Hekimoglu, and Dekker, 2023), prevent stock outs or overstock situations (Gerrits, Topan, and van der Heijden, 2022) and foster continuous process improvement (Hekimoğlu et al, 2022).

Figure 7 illustrates the presence of other CT types identified by interviewees when asked: “Do you see any other type that should be included?” (Question 4.4). It represents CTs that were not identified in the literature or were not identified as a common type of CT but were recognized by practitioners and may be used to improve the SCCT framework. To make it clear, this analysis is presented before the analysis of suggestions regarding the supply chain management CTs because from them, one or another different CT can be identified and may be incorporated in the scope of the end-to-end supply chain CT.

Figure 7: Other types of CTs identified in the interviews



Source: Author.

Among them, risk management CTs stood out. In their context, Respondents 7 and 18, both from the same technology company specializing in CT solutions, explain that while the safety CT prioritizes driver safety to reduce the risk of accidents, security CTs focus on cargo. In this regard, these towers differ from those analyzed in this study, as their primary objective is not to optimize operational performance but to manage risks.

Despite their different focus, these CTs can directly impact operations. Respondent 13 highlighted that a safety CT can influence the supply chain, particularly when a shipment needs to be paused due to tracking issues, such as the absence of GPS mirroring or internal cameras. Overall, while eight respondents acknowledged the existence of safety CTs, only one mentioned operates, in fact, one of them, which may indicate an emerging market trend. Therefore, we recommend future studies to further explore and enhance the understanding of this CT's application.

Five respondents have mentioned the existence of order management CTs. Sharabati, Al-Atrash and Dalbah (2022) and Patsavellas, Kaur and Salonitis (2021) also have mentioned their existence, although not as a separate CT, both see it as an SCCT component. Respondent 19 explains that “it covers the entire process from the order request, including credit availability, product availability, item purchase, receipt, and distribution.” Based on both theoretical and empirical relevance, it was included in the scope of supply chain management CTs.

Providing a slightly different example, Respondent 3 explains that the order management CT that he uses monitors the progress of internal stages up to the invoicing of the shipment. After invoicing, CT focused on transportation tracks the order delivery to the final customer through. In this sense, the distribution not necessarily should be included in the scope of the order management CT, as mentioned by Respondent 19. Nonetheless, we will include this function in the SCCT definition due to its empirical and theoretical background.

Manufacturing CTs have been identified by four practitioners and have also been found in the literature (Vlachos, 2023; Maheshwari *et al.*, 2023). In a manufacturing environment, CTs can offer precise insights into order progress, enabling real-time monitoring of production orders and managing demand admission effectively (Ma, Hekimoglu, and Dekker, 2024). In this research, this CT was considered in the scope of the supply chain management CT definition due to few appearances in the literature as a standalone CT (see Fonseca and Guimarães, 2024). Others illustrate how flexible this technology is to adapt to a company's needs but not provide evidence for further improvements.

Table 12 presents the responses related to CT with a focus on supply chain management. Respondents 3 and 7 indicate that the definition should clarify whether transport execution should be handled by a different CT or not. The current definition already encompasses the idea of delivery to the final customer, but to ensure clarity, it will be improved. Vlachos (2023) highlights that SCCTs originated from logistics CTs and evolved into broader supply chain orchestration tools, integrating demand planning, procurement, manufacturing, and distribution planning to the initial logistic functions. This reinforces that SCCTs focus is on effectively end-to-end supply chain, including transport execution.

Table 12: Responses related to Supply Chain management CTs

Respondent	**Response**
Respondent 3	I understand that the supply chain control tower would extend to transport planning (orchestrating planning to meet all delivery requirements to enable subsequent monitoring). There should be a separate transport control tower to monitor transport execution until the final customer. Logistics and transport should be part of operational planning. The supply chain control tower should include procurement, order management, and logistics and transport planning.
Respondent 7	I would add delivery management to the definition of the supply chain control tower.
Respondent 12	I believe that the essence of the control tower is deviation management, and this is not clearly stated in the definitions. I would highlight that the

	supply chain control tower definition adds an important purpose by mentioning decision-making.
Respondent 16	There could indeed be three separate towers but also suggests the possibility of a single control tower with three distinct cells.
Respondent 17	I would add continuous improvement to the definition. Understands that the order control tower is within the supply chain control tower.
Respondent 19	I prefer the term "logistic network" instead of "supply chain" to better convey the complexity of operations. These integrated towers allow for better real-time understanding of logistical trade-offs and improved synchronization of the supply chain through centralized visibility.
Respondent 20	I see the supply chain control tower encompassing procurement, manufacturing, shipping, transportation, and financial, tax, and fiscal aspects.
Respondent 21	I believe that customer experience should be mentioned in the supply chain control tower.

Source: Author.

Respondent 12 emphasizes that deviation management is not explicitly stated in the definition. Sharabati, Al-Atrash and Dalbah (2022) support this observation by describing SCCTs as visualization systems that detect supply chain deviations and trigger corrective actions. Given its relevance, deviation management was incorporated into the updated definition.

Respondent 16 suggests that rather than three separate CTs, an organization could use a single SCCT with specialized functional areas for inventory, transportation, and supply chain management. While this approach is viable if strong integration exists, it is mandatory ensuring synergy and seamless communication between different CTs (Patsavellas, Kaur and Salonitis, 2021). Thus, while the definition continues to distinguish SCCTs from other CTs, their potential integration within a broader, multi-functional framework was acknowledged.

Respondent 17 suggests adding continuous improvement as a defining characteristic of SCCTs. In this context, Vlachos (2023) describes SCCTs as progressively standardized, flexible, and formalized to optimize planning and execution processes. Additionally, Handfield *et al.* (2020) emphasize that SCCTs should enable ongoing process refinement based on real-time insights and predictive analytics. Given its strong theoretical and empirical support, continuous improvement was incorporated into the definition.

Respondent 19 proposes using the term "logistics network" instead of "supply chain" to reflect operational complexity. While this perspective is insightful, it was not shared by other respondents, indicating that most practitioners align with the traditional "supply chain" terminology. To maintain consistency and ensure alignment with validated frameworks, the term "supply chain" was retained.

Respondent 20 suggests that procurement, manufacturing, shipping, transportation, and financial, tax, and fiscal aspects should be explicitly mentioned. The existing definition already includes procurement, manufacturing, logistics, and transportation planning. Financial and tax elements, while relevant, are indirectly managed through broader supply chain visibility rather than as core SCCT functions, so they were not explicitly added.

Respondent 21 advocates for including customer experience in the definition. Liotine (2019) supports this, stating that SCCTs serve as command centers that enable companies to act closely with suppliers and enhance customer service. Additionally, Sharabati, Al-Atrash and Dalbah (2022) describe SCCTs as synchronizing supply and demand flows to improve service levels for end customers. Given its strong theoretical foundation, customer experience was integrated into the refined definition.

Based on the new perspectives, the updated definition for CTs with focus on supply chain management is: A centralized digital hub that provides visibility (Handfield *et al.*, 2020; Sharabati, Al-Atrash and Dalbah, 2022), coordination (Vlachos, 2023; Ji, Tian, and Gao, 2013), and decision support (Patsavellas, Kaur and Salonitis, 2021; Guidani, Ronzoni, and Accorsi, 2024) over end-to-end supply chain operations, can encompassing demand planning, procurement, order management, logistics, manufacturing, inventory, and transportation (Ji, Tian, and Gao 2013; Sharabati, Al-Atrash and Dalbah, 2022; Vlachos, 2023). It integrates real-time data from various sources allowing deviation management (Sharabati, Al-Atrash and Dalbah, 2022), end-to-end transparency (Handfield *et al.*, 2020), continuous process improvement (Vlachos, 2023), customer service enhancement (Liotine, 2019), and synergy among the supply chain functions.

Table 13 discloses the responses that did not fit the initial categories, bringing novelty to discussion. Respondents 6, 13 and 19 have shed light on a similar perspective. They suggested adopting a flexible CT' definition for one supply chain process or more under monitoring instead of having the proposed static framework in terms of which supply chains functions are encompassed by them. In fact, it would be useful due to increasing technological development that can make the framework's definitions obsolete by time passage.

Table 13: Responses that did not fit the framework of most common CT types

Respondent	Response
Respondent 6	I agree with the definition of the supply chain control tower. Regarding transportation and inventory control towers, I believe these may only be process control towers. I suggest generalizing by calling it a management control tower for a specific process, providing two examples such as transportation and inventory.
Respondent 13	I see the supply chain control tower as the sum of several towers focused on specific processes.
Respondent 19	Highlights that transportation and inventory are functions, and just as with them, there could be control towers for other functions, such as production. The greatest benefit occurs when the scope is expanded to encompass more functions, creating synergy between them. Thus, they believe that functional towers exist (such as transportation and inventory) as well as towers that integrate different functions.
Respondent 20	The inventory and transportation control towers would not be CTs as they do not encompass more supply chain functions.

Source: Author.

Answering their appointments, we believe that their view is already captured by the proposed definition for CTs in the supply chain (see Section 4.1.2), since it is not focused on any specific supply chain function and can be used for both cases. The perspective of these practitioners as well as authors that have studied CTs focused on specific supply chain functions provide support to not consider the observation of Respondent 20 in this work.

Finally, Table 14 summarizes the final updated definition of the three most common types of CT in the supply chain context. All of them have incorporated relevant considerations that have emerged during interviews content analysis, contributing to more robust and adequate definitions.

Table 14: New definitions of the most common types of CTs in Supply Chains

Focus Area	New Definitions	Supporting Authors	Supporting Respondents
Transportation Management	A centralized digital hub focused on providing visibility, coordination, and decision support of transportation activities, enabling deviation management and continuous process improvement. It integrates real-time data from various stakeholders, including shippers, carriers, and regulatory bodies, to provide a holistic view of the entire transportation process. It can encompass planning, routing, execution and scheduling.	Vanvuchelen, Gijsbrechts and Boute (2020); Maneengam and Udomsakdigool (2020; 2021); Alacan and Sencer (2021); Wycislak (2023); Wyciślak and Pourhejazy (2023).	Respondents 8, 12, 13, 17 and 21.

Inventory and Warehouse Management	A centralized digital hub focused on providing visibility, coordination, and decision support over inventory and warehouse operations. It integrates real-time data such as inventory levels, warehouse locations, and order statuses from various sources to allow deviation management, optimize stock accuracy and space, reduce lead times, prevent stock outs or overstock situations, and foster continuous process improvement.	Topan *et al.* (2020); Gerrits, Topan, and van der Heijden (2022); Hekimoğlu *et al.* (2022); Ma, Hekimoglu, and Dekker (2023); Duarte, de Haro Moraes, and Padula (2023); Maheshwari *et al.* (2023); Chen, Cohen, and Lee (2024).	Respondents 2, 8, 12 and 17.
Supply Chain Management	A centralized digital hub that provides visibility, coordination, and decision support over end-to-end supply chain operations, can encompass demand planning, procurement, order management, logistics, manufacturing, inventory, and transportation. It integrates real-time data from various sources enabling deviation management, end-to-end transparency, continuous process improvement, customer service enhancement, and synergy among the supply chain functions.	Ji, Tian, and Gao (2013); Liotine (2019); Handfield *et al.* (2020); Patsavellas, Kaur and Salonitis (2021); Sharabati, Al-Atrash and Dalbah (2022); Vlachos (2023); Guidani, Ronzoni, and Accorsi (2024).	Respondents 7, 12, 16, 17 and 21.

Source: Author.

4.3. CONTROL TOWER CAPABILITIES

Section 4.3 presents the development of the capability framework for CTs within the supply chain context. To this end, first, four capabilities and their descriptions are presented in Section 4.3.1. In Section 4.3.2, the definitions for each one of them are developed. Finally, Section 4.3.3 presents the process of validating and refining the capabilities framework.

4.3.1. Identifying CT capabilities

Following the QCA methodology outlined by Bengtsson (2016), the process of developing categories is presented below using some of the capabilities presented in Table 2 as examples. In this sense, Table 15 shows examples of meaning units, condensed meaning units and sub-categories that resulted from the decontextualization analysis of works. Meaning units, in this work, are phrases or segments that convey specific ideas related to the capabilities in the CT context considering the understanding of capabilities as the combination of processes and tools to deliver a specified outcome.

Table 15: QCA Meaning Units, Condensed Meaning Units and Codes

Meaning Unit	Condensed Meaning Unit	Codes
"The solutions that provide real-time visibility to supply chain risks are fascinating" (Banker, 2021)	Real-time supply chain visibility	Real-time visibility
"We suggest two respective risk quantifiers that can indicate future stockouts" (Hekimoglu, Kök, and Şahin, 2022)	Risk quantifiers for future stockouts	Risk quantifiers
"Support the day-to-day operational planning decisions" (Topan *et al.*, 2020)	Decision support for operational planning	Planning support
"The control tower links man, machines, and methods through IoT, and uses Artificial Intelligence and cloud platforms for decision aid and/or automated decision-making." (Wycislak and Pourhejazy, 2023)	Decision aid / Automated decision-making	Decision support / Automation
"Even before the problem happens, the entire system is alerted, and corrective actions are suggested in CT." (Kulkarni, 2023)	Predictive alerts / corrective actions suggestion	Predictive analytics
"Smart contract is created for executing the terms of every single workflow of a shipment on the platform" (Alacan and Sencer, 2021)	Smart contracts for logistics	Smart contracts
"For repairable spare parts, control towers can serve two distinct functions: generating advance warnings for future stockouts and making repair expediting decisions." (Hekimoglu, Kök, and Şahin, 2022)	Stockout prevention and support expediting decision	Stockout alerts
"Indicators for facilities, lines, and resources like capacity utilization, costs, power, and water consumption, and GHG emissions are plotted in real-time in the DT control tower." (Guidani, Ronzoni, and Accorsi, 2024)	Real-time monitoring of KPIs	KPI monitoring
"SCCT is capable of integrating technologies, processes, and human expertise that serve as supply chain orchestrators" (Wycislak and Pourhejazy, 2023)	Integrate to serve as Supply chain orchestration	Supply chain orchestration

Source: Author.

After identifying the meaning units, in the recontextualization stage, we check the context to ensure all relevant data is included while extraneous information is discarded (Bengtsson, 2016). This stage ensures we have captured the full scope of each capability without losing essential information. As can be seen, each meaning unit can have one or more codes. Next, Table 16 shows examples of the organization of condensed meaning units into codes and then group them into subcategories and categories.

Table 16: QCA Coding System

Code	Subcategory	Category
Real-time visibility	Real-time visibility	Visibility
Predictive analytics	Predictive Insights	Visibility
KPI monitoring	Performance Monitoring	Visibility
Risk quantifiers	Predictive Alerts	Alerting
Stockout alerts	Supply Chain Alerts	Alerting
Decision support	Planning Support	Decision Support
Supply chain orchestration	Coordination and Execution	Decision Support
Smart contracts	Automated Contracting	Automation
Automation	Process Automation	Automation

Source: Author.

Finally, in the fourth stage, we compile the findings into a comprehensive view that connects the final four categories (Visibility, Alerting, Decision Support and Automation) with their implications for CTs. In this sense, below is presented a description of the scope of each capability based on the SLR.

4.3.1.1. Visibility

Achieving visibility is essential for effective decision-making, yet it remains a challenging effort becoming a primary focus for many organizations (Wycislak, 2023). CTs can practically provide the crucial end-to-end visibility needed by serving as a platform for coordination between organizations (Patsavellas, Kaur and Salonitis, 2021). Therefore, the achievement of CT's objectives is a result of effective integration (Maheshwari *et al.*, 2023), which should be the focus of visibility development to improve performance (Wycislak, 2023).

As a result, CT is a central system for collecting, storaging, analyzing and visualizing the real-time progress of the supply chain (Patsavellas, Kaur and Salonitis, 2021; Sharabati, Al-Atrash and Dalbah, 2022). This enables all authorized participants to have visibility over real-time information on inventory, shipments, and material consumption anytime and anywhere (Handfield *et al.*, 2020).

To provide real-time monitoring and granular visibility, CTs require a fine-grained level of traceability all along the chain within each partner (Roch *et al.*, 2015; Patsavellas, Kaur and Salonitis, 2021), which is obtained from IoT systems' sensors and communication devices. These include GPS (Ji, Tian, and Gao, 2013; Banker, 2023), GIS (Guidani, Ronzoni, and Accorsi, 2024), and RFID (Ji, Tian, and Gao, 2013; Roch *et al.*, 2015), among other sensors.

Complementary, the desired visibility from real-time or near real-time information is firstly also achieved through the use of Application Programming Interfaces (API, Banker, 2023) and Electronic Data Interchange (EDI, Vlachos, 2023) to integrate data from Enterprise Resource Planning (ERP), Transportation Management Systems (TMS) and Warehouse Management Systems across the different business units and partners (Liotine, 2019).

In practice, the visualization of all this data occurs through centralized analytic dashboards that identify key performance metrics (Handfield *et al.*, 2020) which can be strategic, tactical and operational performance KPIs, allowing the monitoring and alert generating (Topan *et al.*, 2020). Different from the static traditional ones, these dashboards are dynamic, continuously providing alerts and insights into deviations happening (Kulkarni, 2023) and suggesting corrective actions to realign with organizational strategy (Sharabati, Al-Atrash and Dalbah, 2022).

4.3.1.2. Alerting

In a CT, alerts (triggers or exception messages) are automatically generated and timely sent to the related stakeholders when potential supply chain anomalies are detected (Patsavellas, Kaur and Salonitis, 2021; Gerrits, Topan, and van der Heijden, 2022). Topan *et al.* (2020) defines an alert as any type of notification designed to initiate one of the identified interventions within the supply chain processes.

According to Vlachos (2023), there are different types of alarms, including sensing, stock, fill rate, and criticality alarms. For example, in the spare parts supply chain, Topan *et al.* (2020) consider that alerts are triggered when projected stock levels deviate from pre-defined tactical plans. Similarly, Hekimoğlu *et al.* (2022) propose an alert generation mechanism aimed at predicting future stock outs of repairable parts when external repair expediting is not possible.

Topan *et al.* (2020) affirm that messages are commonly created based on business rules. Duarte, de Haro Moraes, and Padula (2023) point out that although alerts are usually generated using ad-hoc rules or conventional forecasting methods, in real-time monitoring, statistical process controls are employed to produce them. Vlachos (2023) corroborates providing evidence from a company in the health sector that uses statistics like the coefficient of variation to sense demand and supply variations.

Therefore, by integrating data from various sources and generating alerts, the CT can identify bottlenecks, deviations, and exceptional events based on real-time information at specific intervals (periodic review) or in response to particular events (continuous review, Topan *et al.*, 2020). This enables different parts of the organization to achieve specific objectives according to chosen tailored methodologies (Duarte, de Haro Moraes, and Padula, 2023) or to collaborate to orchestrate a joint response to the event (Patsavellas, Kaur and Salonitis, 2021) to maintain desired service levels (Liotine, 2019).

To address the alerts, planners review these notifications and choose an adequate intervention (Topan *et al.*, 2020), such as emergency replenishing stock, rerouting or rescheduling distribution, or activating alternative suppliers (Vlachos, 2023). These interventions are normally reactive (Duarte, de Haro Moraes, and Padula, 2023) and help organizations to realign with its strategy (Sharabati, Al-Atrash and Dalbah, 2022).

Notwithstanding it, Topan *et al.* (2020) and Duarte, de Haro Moraes, and Padula (2023) caution that current CT solutions generate an excessive number of alerts and depend on arbitrary thresholds. They emphasize the need to prioritize exception messages so that planners can concentrate on the most critical issues.

4.3.1.3. Decision support

CTs should equip operators to make decisions and act in response to operational disruptions, while also offering information to support decisions at all levels and accommodating different modes of interaction between CT operators and clients (Liotine, 2019). In this role, to enhance their decision-making capabilities, organizations are increasingly adopting data analytics capabilities (Patsavellas, Kaur and Salonitis, 2021), being data analytics an essential component of CTs (Liotine, 2019).

Vanvuchelen, Gijsbrechts and Boute (2020) affirms that in the transportation industry, CTs use real-time information and analytics to visualize shipments and support replenishment decisions, ensuring smooth freight routing across the network. Additionally, Maheshwari *et al.* (2023) describe CTs' module applied in the pharmaceutical industry supply chin accountable for decision support and forecasting, including digital twin, manufacturing and analytics.

Liotine (2019) affirms that there is a continuous need to use predictive and prescriptive analytics to improve current decision-making processes. Decisions in a CT powered by analytics should be more proactive due to the use of tailored monitoring dashboards and interfaces that rely on information from both internal and external sources (Guidani, Ronzoni, and Accorsi, 2024). The greater the amount of data available for CTs as well as feedback collected from their suggestions, the more accurate and effective the recommendations presented by them will be (Vlachos, 2023).

On the other hand, Topan *et al.* (2020) asserts that despite being well-equipped to provide real-time information, the CTs considered in their study in the spare parts industry lack the analytics functionality needed to accurately assess the impact of interventions and support day-to-day operational planning decisions. As a result, it is possible to understand that there are different levels of decision-making support in CTs.

In the more technological ones, even before the disruption happens, the entire system can be alerted, and corrective actions are suggested (Kulkarni, 2023) due to its what-if simulations and predictive analytics capabilities (Liotine, 2019). In turn, in traditional CTs, where planners often manually analyze anomalies (Topan *et al.*, 2020), there is room for improvement to adopt decision making supporting tools powered by data analytics to present multiple intervention options along with their estimated impacts.

In this field, Sharabati, Al-Atrash and Dalbah (2022) highlight the role of descriptive analytics to deploy better decisions and Vlachos (2023) points out the benefits of employing predictive and prescriptive analytics to create and execute demand, supply, and distribution plans. Patsavellas, Kaur and Salonitis (2021) adds planning and diagnostic analytics capabilities to the previous three, affirming that altogether they are the types of analytics powered by CT.

All these decision analytics will be supported by artificial intelligence, machine learning and optimization models (Liotine, 2019) as well as simulations can be supported by digital twins (Banker, 2023; Guidani, Ronzoni, and Accorsi, 2024). Notwithstanding, Vlachos (2023) showcases the role of experts' knowledge and decision-making skills combined with advanced analytics to generate efficient supply chain planning and execution at all decision levels.

CTs can leverage both strategic, tactical and operational levels (Patsavellas, Kaur and Salonitis, 2021) in response to the supply chain complexities. However, decision support mainly enables tactical and strategic decisions such as proactive planning of procurement, operations and distribution according to market demand, and control over the design of the overall supply chain network can be provided (Ji *et al*, 2013).

Finally, it is relevant to mention that their functioning is far from something static as CTs can be in a continuous improvement process. Vlachos (2023) provides the example of the implementation of a CT that had already reached the second level (tactical) and was working to expand its operations to more suppliers and markets to be ready to redesign the supply chain network whether and when necessary.

4.3.1.4. Automation

Liotine (2019) supports the idea that decision-making should be automated via the CT to the extent that it operates autonomously and can self-correct, significantly reducing the reliance on manual intervention for managing responses and events. The automation of CTs is a result of standardization (Vlachos, 2023) and integration (Patsavellas, Kaur and Salonitis, 2021) of enterprise systems within the same organization or inter-organizations.

In this context, Wyciślak and Pourhejazy (2023) suggested that repetitive decisions at the operational and tactical levels, which are often time-consuming and costly for humans to manage, should be automated. Patsavellas, Kaur and Salonitis (2021) asserts that different business processes within CTs can be arranged in a 'landing' schedule, allowing them to operate automatically without requiring manual intervention.

To reach the end of decision-making automation, the organization needs to establish a foundation for standardizing manual processes (Liotine, 2019). Then, by ensuring the granular and accurate mapping of the supply chain network, the CT itself lays the groundwork for automation, although it does not exclude necessarily human oversight and interactivity (Patsavellas, Kaur and Salonitis, 2021).

On the other hand, Vlachos (2023) provide evidence that the knowledge created by the CT through the cycle of suggest planning and event control activities, predict its possible outcomes, acquire feedback of the reality through the real-time monitoring and improve its decision support tools, made the CT team to learn how to plan, execute, and control supply chain projects better than relying on people expertise.

Overall, Vlachos (2023) provides evidence that the automation and standardization of a CT in the health sector allowed improvement on supply chain projects cost control and Wyciślak and Pourhejazy (2023) demonstrated the possible benefits of dock booking automation in the transport management of a company.

4.3.2. Finding definitions for CT capabilities

After having identified CT capabilities, building on the description done in the previous subsection, we now intend to provide their definitions based on the data captured in the SLR displayed in Section 4.3.1. In this context, visibility figures out as the first and most fundamental capability of CTs, enabling near-real-time visibility to inventory, shipments, and risks (Banker 2021). Achieving visibility is a critical goal for CTs as it allows organizations to gain real-time insights into their supply chain operations, facilitating informed decision-making and rapid response to disruptions (Wycislak, 2023).

Moreover, CTs use different technologies to aggregate and process data from these systems, ensuring seamless coordination and information-sharing across the supply chain (Banker, 2023; Vlachos, 2023). This integration enables business-to-business collaboration, allowing smooth real-time information sharing and enhancing overall supply chain performance (Patsavellas, Kaur and Salonitis, 2021).

However, visibility alone does not build a CT. The second capability of a CT, alerting, comes to provide a focus over the amount of data made available by visibility. Alerting plays a pivotal role in ensuring that supply chain disruptions and inefficiencies are addressed promptly by notifying relevant stakeholders when deviations from expected performance occur (Patsavellas, Kaur and Salonitis, 2021; Gerrits, Topan, and van der Heijden, 2022). To provide this capability, CTs rely on real-time monitoring and statistical process control techniques to generate alerts dynamically, enabling a proactive response to potential issues (Vlachos, 2023).

Another crucial concept in CT, control, is mainly supported by decision-making capabilities when focusing on tactical and strategic decisions. Decision support within CTs provides essential analytical capabilities to enable timely, informed and proactive decision-making across all levels of the supply chain. CTs equip stakeholders with the tools and insights needed to manage supply chain disruptions, optimize resource allocation, and improve performance outcomes (Liotine, 2019; Patsavellas, Kaur and Salonitis, 2021).

CTs can utilize a combination of descriptive, predictive, and prescriptive analytics to support decisions (Patsavellas, Kaur and Salonitis, 2021). However, the methodology employed in decision support varies based on the technological sophistication of CT. For instance, in the pharmaceutical industry, CTs integrate digital twins, analytics, and forecasting models to enhance decision-making (Maheshwari *et al.*, 2023). In contrast, traditional CTs may rely on manual interventions supported by basic dashboards and reporting tools (Topan *et al.*, 2020), following predefined workflows.

Finally, after acquiring the previous capabilities, automation showcases as a necessary capability to allow the continuous development of all the previous capabilities. Automation is a key enabler of supply chain efficiency, allowing CTs to execute decisions with minimal human intervention while ensuring consistent and optimized performance (Vlachos, 2023; Patsavellas, Kaur and Salonitis, 2021).

According to Wyciślak and Pourhejazy (2023), repetitive decisions at operational and tactical levels, such as order processing and inventory replenishment, should be automated first to free up resources for more strategic activities. For more complex activities, CT automation is achieved through a combination of rule-based and AI-driven processes, where standard rules handle routine tasks, while AI adapts to dynamic market conditions by learning from historical data (Vlachos, 2023). Table 17 presents the CT capabilities definition resulting from the joining of the main concepts and perspectives evidenced in the SLR of each capability.

Table 17: Capabilities, Definitions and Key supporting authors

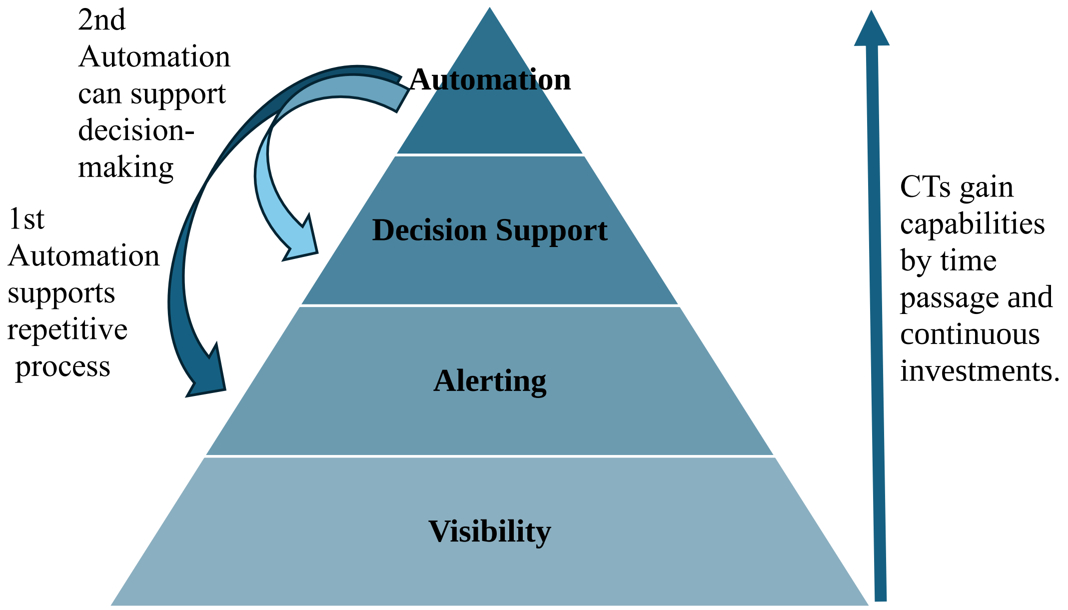
Capability	**Definition**	**Key Supporting Authors**
Visibility	The ability to access and view real-time or near real-time data across the entire supply chain. This is achieved through the integration of data sources, enhancing coordination and information sharing among supply chain partners.	Vlachos (2023), Banker (2021); Topan *et al.* (2020), Patsavellas, Kaur and Salonitis (2021), Liotine (2019), Wycislak (2023).
Alerting	Any type of notification designed to initiate one of the identified interventions within the supply chain processes.	Topan *et al.* (2020), Duarte, de Haro Moraes, and Padula (2023), Vlachos (2023), Patsavellas, Kaur and Salonitis (2021), Gerrits, Topan, and van der Heijden (2022).
Decision Support	The use of tools, technologies, and methodologies to assist in making informed, effective, and timely decisions. It will vary according to the degree of employed technology in each control tower.	Vlachos (2023), Topan *et al.* (2020), Liotine (2019), Patsavellas, Kaur and Salonitis (2021), Maheshwari *et al.* (2023).
Automation	The use of technology to automate the decision-making processes, ranging from repetitive operational and tactical	Vlachos (2023), Topan *et al.* (2020), Duarte, de Haro Moraes, and Padula (2023), Patsavellas,

	decisions to strategic decisions based on developed intelligent assets.	Kaur and Salonitis (2021), Wyciślak and Pourhejazy (2023), Liotine (2019).

Source: Author.

It is important to mention that the final framework presented above has an evolutionary rationale. Figure 8 illustrates this function. The main idea is that CT gains more capabilities by time passage and continuous investments. Hence, visibility is needed to establish a data tower, making all the needed data codified and available. Then, from pre-defined business rules and observation of repetitive events, alerts are programmed to allow adequate and fast responses to disruptions. In this sense, they can support decision making but at an operational level and, most times, following predefined workflows.

Figure 8: CTs' capabilities framework rationale



Source: Author.

Moreover, based on the historic data available, which depends on time passage, as well as the occurrence of alerts and the efficacy of the interventions, data-driven decisions in tactical levels can increase the efficiency of the overall process under the CT scope, ultimately supporting decision-making at the strategic level. Finally, automation takes place first in the simplest and most routine processes. By the time, depending on the level of technology implemented in the CT, which depends on continuous investments, automation may suggest decision-making in order to prevent possible disruptions to the supply chain based on artificial intelligence and machine learning tools.

Summing up, there is an intrinsic relation among the capabilities. While visibility supplies alerts and decision making with data, automation may be applied to reduce human intervention in managing alerts and decision support or even to share and maintain actualized tailored dashboards for different departments of the same company.

4.3.3. Validating and refining CT' capabilities framework based on interviews data

During the interviews, respondents were asked to express their agreement with the proposed framework and suggest potential refinement (See Appendix B for questions employed and Appendix D for a summary of responses). Overall, among the 21 respondents, 47,6% totally agreed (Respondents 1, 3, 4, 6, 12, 14, 15, 16, 19, and 21) and 52,4 % partly agreed (Respondents 2, 5, 7, 8, 9, 10, 11, 13, 17, 18, and 20) with the proposed framework, what indicates that the agreement level was reached, and the framework is valid.

Only three respondents did not make additional comments, so the interviews provided a significant amount of data for analysis and further model refinement. Hence, the primary data collected through interviews was analyzed using the DCA process (Hsieh and Shannon, 2005). The capabilities framework was used as an initial coding guide, categorizing interviewees' responses under predefined themes while remaining open to emerging insights. The following analysis will systematically assess each capability individually, followed by a discussion of emerging insights that did not fit within any single category.

Table 18 presents the observations of visibility capability. Respondents 9 and 16 mention the necessity to provide a focus for the CT' visibility. Its dashboards should incorporate the KPIs related to the most relevant part of operations. This perspective can be considered new compared to the revised academic literature. Although authors mention that CTs handle large amounts of data (Gerrits, Topan, and van der Heijden, 2022), they do not make this clarification that it could hinder rather than improve operations. This empirical perspective was included in the framework.

Table 18: Respondent's comments and suggestions about visibility capability

Respondent	Visibility
5	I believe visibility should be centralized.
7	I would replace "data" with "the ability to visualize the operation in real-time" in the visibility definition. I believe visibility can be achieved through telemetry, trackers, or mobile apps.
8	I believe information should be real-time, as near real-time is not sufficient.
9	I believe visibility should focus on what is most critical for the business—what truly adds value.

11	Visibility should help identify patterns.
13	I would add "historical data" after "near real-time."
14	I would place visibility as the last level.
16	I believe the control tower will generate a large amount of data, but it's essential to have clarity on which KPIs truly add value to the operation.
19	Visibility is linked to tracking data capture. Technologies such as GPS, RFID, and mobile apps provide visibility, but this alone is not enough.

Source: Author.

For Respondents 7 and 8, CT should work in real-time. In truth, this is already a perspective that many other participants have mentioned during their interviews. Corroborating this view, many other authors (see Table 1) also have this perspective, and only Banker (2021) have mentioned near-real-time. Due to numerous considerations regarding this CT characteristic, it was considered to refine the framework.

Respondent 5 suggests that visibility should be centralized. While this aligns with the fundamental role of a CT as a central hub for data aggregation (Sharabati, Al-Atrash and Dalbah, 2022), this characteristic is already implicit in most definitions of CTs and does not introduce novel refinement. Therefore, this perspective was not considered for refinement.

Respondent 11 stated that visibility should help identify patterns. While this is a valuable insight, it represents an outcome of visibility rather than a defining characteristic of the capability itself. Academic literature, such as Patsavellas, Kaur and Salonitis (2021), supports the role of visibility in uncovering trends through historical and real-time data. However, to keep the definition straightforward and focused on the capability rather than its results, this perspective was not incorporated into the framework.

Respondent 13 suggests adding "historical data" after "near real-time" in the definition of visibility. This perspective aligns with academic sources like Wycislak (2023) and Patsavellas, Kaur and Salonitis (2021), which emphasize that real-time visibility is valuable but must be supplemented with historical data for improved forecasting and decision-making. Considering the empirical and academic support, this refinement was included in the novel framework.

Respondent 14 mentions that visibility should be placed as the "last level." However, Liotine (2019) describes visibility as the core function that allows monitoring of supply chain operations, deviations, and exceptions, enabling proactive interventions. If visibility were positioned after automation, it would contradict the logical flow of data-driven decision-making, where automation is typically built upon an already established data foundation. Therefore, it was not incorporated into the framework.

Respondents 7 and Respondent 19 make similar observations about the sources of visibility data. Although the adequacy and relevance of their appointments, we choose not to include it in the capability definition is to keep it straightforward. This information as well as other complementary and relevant information are disclosed in Section 2.1.1. Therefore, it will not be incorporated into the framework. Respondent 19 also mentions that "visibility alone is not enough," an argument that is already implicit in the literature. Authors such as Sharabati, Al-Atrash and Dalbah (2022) emphasize that visibility is an enabler that must be integrated with other capabilities to be effective. Given this, it was not considered but remains an important underlying principle of the framework.

As a result, considering all the other comments, the new definition of visibility capability is: The ability to access and analyze real-time and historical data across the supply chain, ensuring a focused and meaningful representation of key performance indicators. It enhances coordination and information sharing among supply chain partners through data integration.

Table 19 presents the observations of alerting capability. Regarding it, three participants (Respondents 9, 15 and 16) have mentioned that the number of alerts should be well considered to reflect the most relevant operational business to make monitoring meaningful. Following their view, Duarte, de Haro Moraes, and Padula (2023) mention that CT generates too many alerts and Topan *et al.* (2020) asserts that alert generations should be tailored to their operational needs. This perspective was incorporated into the framework.

Table 19: Respondent’s comments and suggestions about alerting capability

Respondent	**Alerting**
2	I suggest mentioning risk management aspects in alerts (focusing more on security).
5	I see alerts more as a decision-support tool rather than a capability and think they should be included under automation.
7	Alerts should include prioritization.
9	Alerts should be defined to ensure they are relevant to operations.
11	Alerts should incorporate process improvements.
12	I would replace the term "alerts" with "triggers."
13	I believe an escalation list and a decision tree should be included as scripts for handling alerts.
15	I see the need to prioritize alerts and establish a decision matrix for each one. In my view, the number of alerts should depend on the operation.

16	Alerts should be configured to allow prioritization and rationalization according to the operation, making monitoring meaningful.
19	It's necessary to compare these "traces" with a standard. From this comparison, an automatic alert is triggered if something goes wrong—this is the essence of monitoring. However, alerts alone are not enough; there must be an escalation procedure (escalation list and decision tree) to address the issue.
20	Alerts should be part of visibility.
21	Alert prioritization should be added to it.

Source: Author.

Next, four practitioners (Respondents 7,15,16 and 21) pointed out the necessity of prioritizing the excessive number of notifications to remain focused on the core business under monitoring, because without them planners can become overwhelmed resulting in inefficiencies (Topan *et al.*, 2020). This consideration aligns with Duarte, de Haro Moraes, and Padula (2023), who emphasize the need for prioritization frameworks to help planners concentrate on high-impact alerts, reducing cognitive load and improving operational efficiency. This meaningful perspective was used to refine the framework.

Moreover, the necessity of clear procedures to address the problem that has triggered the alerts is highlighted by respondents 13 and 19. In this context, Patsavellas, Kaur and Salonitis (2021) corroborate the practitioner's perspective while affirming that CTs utilize workflow tools to coordinate a well-structured response to an event. This opinion was also mentioned by Respondents 7 and 8, which mention the existence of standardized escalation lists and decision trees to respond to issues. As a result, due to their empirical relevance, it was considered to improve the alerting definition.

Analyzing other comments, the suggestion of Respondent 2 takes into consideration the context of a CT with focus on ensuring safety for truck drivers, a CT type that is discussed in Section 4.3.2. However, as it was not considered in the scope of the study, the perspective was not incorporated in the definition.

The two different perspectives of Respondent 5 led the researcher to realize that a more detailed explanation should be provided in the next capabilities. In this dissertation we considered that alerts can be seen as a decision support tool but at operational levels, primarily focused on reactive measures, whereas the Decision Support capability refers to proactive actions. Additionally, alerts are indeed automatic, but this capability relates to how a CT enables event management in the supply chain process. Otherwise, visibility could also be considered part of automation, as it provides real-time data automatically.

Respondent 11 mentions that “Alerts should incorporate process improvements”. However, this perspective is included in the Decision Support capability as process improvements are seen as a result of data driven decision making at tactical and strategic level based on the historical data storage in the CT. For Respondent 12, the label “alerting” should be replaced by “triggers”. Although Gerrits, Topan, and van der Heijden (2022) see them as synonymous, Duarte, de Haro Moraes, and Padula (2023, p. 2) asserts that “an alert […] is any form of notification that is generated with the intent of triggering any one of their identified interventions into the supply chain processes”. In this sense, we still see alerting as a more appropriate label for this capability.

In the view of Respondent 20, “Alerts should be part of visibility”. However, they are separated because, in literature, the former is seen as a dynamic tool while the latter has a static characteristic (Kulkarni, 2023). Moreover, Wycislak (2023, p. 1447) affirms that “visibility is only an enabler for further improvements, and real-time data can only suggest opportunities”, reinforcing the idea that visibility alone does not create impact unless it is connected to other capabilities.

Based on the explanation provided for each of the comments made only once, they were not considered to refine the proposed framework. As a result, considering all the other comments, the new definition of alerting capability is: The ability to generate and prioritize notifications that can trigger relevant interventions in supply chain processes. Alerts should be tailored to operational needs, avoiding excessive notifications and ensuring clear response procedures for effective decision-making.

Table 20 presents the observations of decision support capability. Respondent 2 suggested adding operational resilience and accuracy in problem resolution as key outcomes of decision support due to its importance to business. This aligns with Chen, Cohen, and Lee. (2024), who pinpoint responsiveness and resiliency as consequences of optimized decisions to manage the supply chain process. However, given that this is an outcome of the capability, this perspective was not incorporated into definition to keep it straightforward.

Table 20: Respondent’s comments and suggestions about decision support capability

Respondent	**Decision Support**
2	I would highlight operational resilience and the accuracy of problem resolution as outcomes.
7	I suggest adding data-driven decision-making to decision support and renaming it to dashboards and KPIs.
8	I consider electronic fences and Power BI to be the most commonly used tools.
13	I see predictive capabilities based on historical data as essential.

Source: Author.

Respondent 7 made two suggestions. Replace decision for “data-driven decision-making” and rename the capability to "dashboards and KPIs". The first was used in the framework refinement because it adds a well-established concept of literature. CT supports data-driven decision-making for everyone who needs it to make informed decisions (Handfield *et al.*, 2020). However, the second was not incorporated, as dashboards and KPIs are tools that facilitate decision-making (Kulkarni, 2023) rather than define the capability itself.

Respondent 8 mentioned that specific tools, such as electronic boundaries and Power BI, are commonly used in decision support. While these tools enhance decision-making, they represent technological enablers of visibility supporting decisions rather than defining characteristics of decision support. Given that similar information is disclosed in section 2.1.1, this perspective was not considered for refinement but can be mentioned as examples in the discussion.

Respondent 13 emphasized the importance of predictive capabilities based on historical data. This aligns with multiple academic sources, such as Liotine (2019) and Topan *et al.* (2020), which highlight the evolution of decision support from reactive to predictive analytics. Predictive capabilities are essential for enhancing forecasting, risk mitigation, and proactive intervention, making this perspective highly relevant (Patsavellas, Kaur and Salonitis, 2021). This perspective was incorporated into the refined definition.

As a result, the perspectives that provide new insights into the current framework, the new refined definition of decision support capability is: The use of tools, technologies, or methodologies to assist in data-driven decision-making, ensuring informed, effective, and timely actions. Depending on the analytical sophistication of each CT, decision support can include predictive capabilities, forecasting, risk mitigation, and proactive intervention based on historical data.

Table 21 presents the observations of automation capability. Respondent 4 emphasized that there is no fully autonomous decision-making, but rather automated tools that assist in decision-making. This aligns with the literature, particularly Liotine (2019), who states that automation in CTs is not about replacing human decision-making but enhancing it through technology. This perspective was incorporated into the refined definition, ensuring that automation is framed as a support system rather than a replacement for human expertise.

Table 21: Respondent’s comments and suggestions about automation capability

Respondent	Automation
2	I see productivity improvement as an important aspect.
4	I believe there is no automatic decision-making, but there are automated tools that assist in the decision-making process.
8	Automation, in my view, should be used for routing and handling alerts.
10	Automation needs to have a clear focus.
17	I believe achieving the fourth level depends on operational maturity and continuous investment in technology.
19	Automation, which in the future will involve machine learning and AI, but currently, it focuses more on repetitive processes.

Source: Author.

Respondent 8 stated that automation should be used specifically for routing and handling alerts. While this is true for some types of CTs, it is too narrow, as automation also plays a role in process optimization, and workflow execution (Patsavellas, Kaur and Salonitis, 2021). In this sense, since the proposed definition should apply to all CTs, this perspective was not incorporated into the general framework.

Respondent 10 noted that automation must have a clear focus. To determine whether this is necessary refinement, we searched for supporting literature. Vlachos (2023) and Duarte, de Haro Moraes, and Padula (2023) discuss how automation in CTs is most effective when it is strategically implemented with clear objectives, preventing unnecessary complexity and inefficiencies. Given this alignment with academic insights, this perspective was incorporated into the refined definition, emphasizing that automation should be purpose driven.

Respondent 17 suggested that achieving full automation depends on operational maturity and continuous investment in technology. This is a valid point, aligning with studies like Vlachos (2023), which highlight that automation progresses through standardization, integration, and gradual implementation of advanced technologies such as AI and machine learning. While this is an important insight, it was not used as it describes the evolution of automation rather than defining its core functions.

Respondent 19 mentioned that automation currently focuses on repetitive processes but will eventually involve AI and machine learning. This aligns with Liotine (2019), Vlachos (2023) and Patsavellas, Kaur and Salonitis (2021), who discuss the gradual shift from rule-based automation to intelligent automation, with a concurrent reduction of manual human intervention. However, since this has already been covered in Section 2.1.1, it was not incorporated again in this section.

As a result, the perspectives that provide new insights on the current framework, the new refined definition of automation capability is: The purpose-driven use of technology to automate supply chain processes, reduce manual intervention, and assist decision-making, ranging from repetitive operational to tactical and strategic decisions.

It is important to mention that, according to Elo and Kyngäs (2008), during DCA analysis new categories can emerge. Therefore Table 22 presents observations that do not fit initial categories and might lead to the creation of other categories.

Table 22: Respondent’s comments and suggestions about that did not fit the framework

Respondent	Others
2	I also identify a fifth capability related to customer experience, which results from an optimized supply chain that positively impacts the customer.
9	I also think that people and their business knowledge should be considered a capability.
10	In my opinion, traceability should come before visibility.
11	I would include people before visibility.
16	I see a middle ground between visibility and alerts in defining what actions to take.
17	I would include an earlier capability, such as process standardization and work instructions.
18	I don't see them as capabilities but rather as scopes of action. In my opinion, the supply chain tower should only include transportation planning. Once the vehicle arrives at the dock for loading, it should fall under the transportation tower until it reaches the final customer.
20	I think traceability should be included before visibility.

Source: Author.

Respondent 2 suggested that customer experience should be included as a capability. While this is an important aspect, we see customer experience as an outcome of a well-functioning CT, which enables high service levels as appointed by Respondents 12,14 e 21. In this context, Patsavellas, Kaur and Salonitis (2021) asserts that since all supply chain partners can be dynamically connected through the SCCT, customers receive quicker, more efficient, and highly responsive service. Therefore, while relevant, it was not incorporated into the framework as a separate capability.

Respondents 9, 11, and 17 proposed that people and their business knowledge, as well as process standardization and work instructions, should be included as capabilities. While people and structured processes are crucial for the effectiveness of CTs, literature widely considers them as pillars that support the capabilities rather than capabilities themselves (Sharabati, Al-Atrash and Dalbah, 2022; Patsavellas, Kaur and Salonitis, 2021; Maheshwari *et al.*, 2023; Vlachos, 2023; Wycislak and Pourhejazy, 2023). CTs rely on skilled professionals and standardized workflows, but these elements enable capabilities rather than define what a CT does. Therefore, they were not included in the framework as distinct capabilities.

Respondents 10 and 20 suggested that traceability should come before visibility as a separate capability. However, Sharabati, Al-Atrash and Dalbah (2022) and Kulkarni (2023) describe traceability as a function within visibility, enabling organizations to track, monitor, and analyze goods movement in real-time, rather than another capability. Given this, we did not create another category of capability with traceability.

Respondent 16 suggested that there is an intermediate step between visibility and alerting for defining actions. However, Patsavellas, Kaur and Salonitis (2021) highlights that structured workflows and response coordination are already integral to the alerting capability, ensuring that alerts lead to well-defined actions. Given this, the perspective will not be incorporated into the framework, as it is already addressed within alerting.

Respondent 18 argued that CTs should be limited to transportation planning, excluding other supply chain functions. However, academic literature and industry practices demonstrate that CTs operate across multiple domains, including inventory management, supply chain execution, and end-to-end visibility (Duarte, de Haro Moraes, and Padula, 2023; Banker, 2023). Given this broader role, this perspective does not align with academic insights or industry trends and was not incorporated into the framework.

Finally, Table 23 summarizes the refined definitions of all the capabilities. Regarding them, one could mention that there are new concepts in the definitions that were not clearly mentioned by practitioners. Explaining their origin, they result from the exercise of search for alignment between empirical and theoretical data, that allowed the acknowledgement of new perspectives on some articles that would not have been noticed yet.

Table 23: Summary of Control Towers Capabilities

Capability	Definition	Supporting Authors	Supporting Respondents
Visibility	The ability to access and analyze real-time and historical data across the supply chain, ensuring a focused and meaningful representation of key performance indicators. It enhances coordination and information sharing among supply chain partners through data integration.	Liotine (2019), Topan *et al.* (2020), Banker (2021), Patsavellas, Kaur and Salonitis (2021), Vlachos (2023), and Wycislak (2023).	Respondents 7, 8 ,9, 13 and 16
Alerting	The ability to generate and prioritize notifications that can trigger relevant interventions in supply chain processes. Alerts should be tailored to operational needs, avoiding excessive notifications and ensuring clear response procedures for effective decision-making.	Topan *et al.* (2020), Patsavellas, Kaur and Salonitis (2021), Gerrits, Topan, and van der Heijden (2022), Duarte, de Haro Moraes, and Padula (2023), and Vlachos (2023).	Respondents 7, 9 13, 15, 16, 19 and 21
Decision Support	The use of tools, technologies, or methodologies to assist in data-driven decision-making, ensuring informed, effective, and timely actions. Depending on the analytical sophistication of each control tower, decision support can include predictive capabilities, forecasting, risk mitigation, and proactive intervention based on historical data.	Liotine (2019), Topan *et al.* (2020), Patsavellas, Kaur and Salonitis (2021), Maheshwari *et al.* (2023), and Vlachos (2023).	Respondents 7 and 13
Automation	The purpose-driven use of technology to automate supply chain processes, reduce manual intervention, and assist decision-making, ranging from repetitive operational to tactical and strategic decisions.	Liotine (2019), Topan *et al.* (2020), Patsavellas, Kaur and Salonitis (2021), Duarte, de Haro Moraes, and Padula (2023), Vlachos (2023), and Wyciślak and Pourhejazy (2023).	Respondents 4 and 10

Source: Author.

5. DISCUSSION

The following section discusses both the theoretical and practical implications of our results, detailing how examining CTs foundational concepts significantly enriches CTs in supply chain literature. Additionally, it establishes a foundation for future research.

5.1. Theoretical contributions

This study represents a significant advancement in the academic literature on CTs by addressing previously identified conceptual and structural gaps. The main theoretical contributions can be organized into three areas: (i) CTs conceptual definition, (ii) structuring of fundamental capabilities, and (iii) classification of the most common types of CTs.

One of the most prominent gaps found in literature is the absence of a robust and widely accepted academic definition of CTs in the supply chain. As previously discussed, many studies (as in Topan *et al.*, 2020, and Gerrits, Topan, and van der Heijden, 2022), rely on definitions from consultancy firms, highlighting the need for a conceptual framework grounded in academic research.

This study addressed this gap through a SLR and the application of DCA on interviews with industry practitioners. As a result, the proposed definition reflects the consensus between academics and professionals. The study further clarifies that although CTs may evolve to provide strategic support, their primary initial function is focused on operational efficiency.

Another relevant contribution is the structuring of the essential capabilities of CTs, organized into four main pillars: visibility, alerting, decision support, and automation. While the literature has addressed some of these capabilities in a fragmented manner (Liotine, 2019; Patsavellas, Kaur and Salonitis, 2021; Vlachos, 2023), this study was pioneering in consolidating them within a cohesive and empirically validated framework.

The research demonstrated that these capabilities have an evolutionary character, where visibility serves as the foundational capability, followed by the implementation of alerts to notify deviations and support quick responses. Decision support emerges as the next stage, as historical data and analytical intelligence are incorporated. Finally, automation represents the most advanced stage, where repetitive, rule-based decisions are progressively handled by intelligent systems.

Finally, continuing the categorization proposed by Fonseca and Guimarães (2024), this study reinforces the existence of three main categories of CTs in the supply chain: transportation management, inventory and warehouse management, and integrated supply chain management.

Although different authors have individually explored some of these categories (Liotine, 2019; Topan *et al.*, 2020; Maneengam and Udomsakdigool, 2021), this study unifies them into a comprehensive framework, facilitating comparison and differentiation among CT types. Additionally, the research revealed that CTs can coexist within a company, and their integration can generate significant operational synergies. Thus, this study provides a novel conceptual framework that can serve as a foundation for future research on the applicability and evolution of CTs in supply chain management.

5.2. Practical contributions

In addition to theoretical advancements, this research provides direct implications for companies and professionals involved in the implementation and management of CTs. The main practical contributions can be organized into four areas: (i) check guidelines for implementation, (ii) strategic role of CTs, (iii) operational challenges and recommendations, and (iv) impact on organizational performance.

Although it is not the primary objective, the findings of this research offer a practical model for checking the evolution of CTs implementation. The capability structure suggests that organizations should begin by developing operational visibility, ensuring the integration of data from multiple sources before advancing to alerts, decision support, and automation. Furthermore, interviews with professionals revealed the need for a selective focus on strategic KPIs, avoiding excessive data overload that could make CTs ineffective due to lack of clear operational direction.

While CTs are often adopted to solve immediate operational challenges, the results indicate that their strategic impact can grow over time. As observed in the interviews, many companies initially implement CTs to improve operational efficiency but later develop capabilities that support tactical and strategic decision-making. This indicates that companies can utilize them not only for problem-solving but also for enhancing strategic planning, risk management, and cost optimization.

In this context, while companies recognize benefits like cost reduction and operational efficiency, there is no standardized approach to quantifying their financial impact, lacking a structured return on investment measurement. Future research should develop structured methodologies for evaluating cost savings, efficiency gains, and financial returns.

Regarding operational challenges, despite the numerous benefits of CTs, their adoption presents several operational challenges that organizations must address to maximize their effectiveness. One of the primary challenges is system integration, as many companies still rely on legacy systems that do not easily support real-time data sharing. Without integration between ERP, TMS and WMS systems (depending on the focus of the CT) achieving the full potential of CTs becomes difficult. Organizations must prioritize APIs and cloud-based solutions to enable data interoperability and streamline supply chain operations.

Another major challenge is the lack of standardized processes within organizations poses a significant barrier to the full adoption of CTs. Without predefined workflows and clear escalation procedures, companies struggle to automate decisions and improve operational efficiency. Standardization is particularly important when implementing alerts, decision-support and automation capabilities within CTs, as it ensures that corrective actions are executed properly. To overcome this challenge, organizations should invest in well-documented process guidelines, and employee training to align CT operations with business objectives.

Furthermore, the excess of alerts, which, if not properly managed, can overwhelm managers and decision-makers with excessive notifications. Several professionals interviewed in this study highlighted that CTs sometimes generate too many alerts, making it difficult to distinguish between critical issues and minor deviations. To mitigate this, organizations should implement prioritization mechanisms that filter alerts based on severity and relevance, ensuring that planners and managers focus on the most urgent and impactful situations.

Finally, it is paramount that the adoption of CTs has a direct impact on organizational service levels, as evidenced by both literature findings and insights from industry professionals. One of the most significant benefits is cost reduction, particularly in logistics and transportation management. Studies and interview responses confirm that CTs contribute to lower transportation costs by optimizing route planning, shipment consolidation, and carrier selection.

Beyond cost efficiency, CTs also play a critical role in enhancing operational performance by reducing response times and improving resource utilization. By integrating real-time monitoring with decision-support tools, organizations can proactively manage disruptions, improve lead times, and optimize inventory allocation. This results in increased supply chain responsiveness, ensuring that companies could better adapt to fluctuating demand patterns and unexpected events such as supplier delays or transport issues.

Another key impact of CT adoption is improved interdepartmental collaboration. Many supply chain inefficiencies stem from a lack of coordination between departments such as logistics, procurement, inventory management, and customer service. CTs address this issue by centralizing supply chain data, providing customized views of data to all interested stakeholders. This fosters a more synchronized approach to supply chain management, reducing silos and enhancing overall decision-making efficiency.

Additionally, companies that implement CTs can experience higher levels of customer satisfaction due to improved service levels. Real-time order tracking, optimized delivery schedules, and proactive issue resolution contribute to better on-time performance and more reliable supply chain operations. This is particularly crucial for businesses operating in competitive markets, where meeting customer expectations for speed, transparency, and efficiency is essential for maintaining market leadership.

6. FINAL CONSIDERATIONS

This dissertation aimed to establish a clear conceptual foundation for CTs in the context of supply chain management by addressing three key research questions: (i) defining what a CT is, (ii) categorizing the most common types of CTs, and (iii) identifying and structuring its capabilities. Through a SLR and a DCA of 21 practitioner interviews, this study has provided significant theoretical contributions and practical insights into the development and application of CTs.

Findings confirm that CTs operate as centralized digital hubs, integrating technology, processes, and people to provide visibility, control, and decision support across supply chain operations. The research also structured CT capabilities into four key areas - Visibility, Alerting, Decision Support, and Automation - demonstrating that they develop progressively as CTs mature. Visibility serves as the foundational layer, followed by alerting mechanisms to identify deviations, decision support for proactive planning, and automation to enhance efficiency and minimize manual interventions.

Furthermore, this study reinforced the existence of three primary focus areas of CTs: (i) Transportation Management, which focus on shipment tracking, route optimization, and deviation management; (ii) Inventory and Warehouse Management, which emphasize stock level monitoring, warehouse space optimization, and demand forecasting; and (iii) Supply Chain Management, which integrate end-to-end visibility across procurement, manufacturing, logistics, and customer service. The validation process through industry practitioners confirmed the relevance of these categories, while also highlighting the potential for hybrid models where companies consolidate multiple CTs into a single integrated system.

A key theoretical contribution of this study is the alignment between academic literature and industry practice, addressing the lack of conceptual clarity in existing research. While academia often presents CTs as strategic enablers, practitioners primarily view them as operational platforms designed for efficiency improvements and cost reductions. This discrepancy underscores the need for companies to consider the long-term strategic value of CTs, rather than limiting their focus to immediate operational benefits.

Regarding practical implications, this research underscores that for effective CT implementation there is a need for meeting key requirements, such as system integration and interoperability, process standardization and employees training, to yield tangible outcomes. Addressing these requirements enables organizations to reduce costs, optimize supply chain coordination and responsiveness, and improve performance and customer experience levels.

Regarding the limitations that must be acknowledged, first, the SLR was made based on only two databases (Scopus and Web of Science), which may limit the range of articles in the analysis. Secondly, as the interviews were all made in Brazil, its result may not be generalized. Moreover, although 21 practitioners were sufficient to data saturation in this research, it may have limited the breadth of perspectives captured.

Given that this dissertation proposes a novel definition for CTs in the supply chain context, future research should include a validation process through expert panels to further assess the accuracy, applicability, and completeness of this definition. Another relevant area for future research is the study of Safety and Security CTs. Some practitioners highlighted that CTs designed specifically for safety monitoring - such as ensuring driver security or tracking potential risks in supply chain operations - could have a significant impact. However, as noted in this research, very few CTs currently include such functionality. Future studies should investigate the potential applications, benefits, and challenges of implementing these types of CTs, particularly in industries with high-risk supply chain operations.

Moreover, while companies recognize benefits like cost reduction and operational efficiency, there is no standardized approach to quantifying their financial impact, lacking a structured return on investment (ROI) measurement. Future research should develop structured methodologies for evaluating cost savings, efficiency gains, and financial returns, ensuring data-driven justifications for CT adoption and optimization.

In conclusion, this dissertation has contributed to the formalization of CTs in supply chain management by providing a structured framework for their definition, capabilities, and classification. It bridges the gap between academic research and industry applications, offering practical guidance for organizations looking to implement or enhance their CT solutions. As supply chains become more complex and data-driven, CTs will continue to evolve, playing a critical role in enhancing visibility, coordination, and decision-making. However, their transition into fully autonomous, AI-driven platforms will require further technological advancements, organizational adaptation, and academic exploration.

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APPENDIXES

Appendix A – Profile of interviewed practitioners

Practitioner	Sector	Knowledge Level*	Experience in CTs
Respondent 1	Food	B	0,5
Respondent 2	Energy	C	0,6
Respondent 3	Pulp and paper	B	1,2
Respondent 4	Food	C	1,5
Respondent 5	Cosmetics and Beauty	C	2
Respondent 6	Retailer	C	2,5
Respondent 7	Consultancy	C	3
Respondent 8	Consultancy	B	3
Respondent 9	Logistics Operator	B	3,5
Respondent 10	Food	B	4
Respondent 11	Food	C	4
Respondent 12	Logistics Operator	C	4
Respondent 13	Energy	B	4
Respondent 14	Consultancy	B	6
Respondent 15	Consultancy	C	8
Respondent 16	Fertilizer	C	10
Respondent 17	Rental	C	12
Respondent 18	Consultancy	C	15
Respondent 19	Consultancy	C	21
Respondent 20	Chemicals	C	5,5
Respondent 21	Consultancy	B	8

* B) My knowledge comes from my current activity.
C) My knowledge comes from a past activity, but I keep myself updated.

Appendix B – Interview script

Phase		Questions	
1.0	Introduction	1.1	Brief summary of the research purposes and how the data will be used.
		1.2	Objective of the interview.
		1.3	Ensure anonymity and confidentiality.
2.0	Introductory Questions	2.1	What organization do you work for?
		2.2	What is your current role?
		2.3	How long have you been working with Control Towers?
		2.4	What level of knowledge do you consider yourself to have regarding control towers in the context of the supply chain?
3.0	Control Towers' Function and Infrastructure	3.1	How do you use control towers in your daily operations?
		3.2	Could you describe how the tower operates in terms of infrastructure?
		3.3	Does it use data clouds?
		3.4	Does it integrate with ERP and other companies' systems?
4.0	Control Towers' Focus Areas	4.1	Based on your experience, do these three types of control towers correspond to what currently exists in the supply chain?
		4.2	Would you make any changes to these categories?
		4.3	Do the definitions match your understanding of each type?
		4.4	How could they be improved?
		4.5	Do you see any other type that should be included?
		4.6	Based on this framework, how do you classify your control tower?
5.0	Control Towers' Capabilities	5.1	Does the use of a control tower bring any capabilities to your organization? Which ones?
		5.2	Based on your experience, do you believe these capabilities are applicable to control towers in general?
		5.3	Is there any capability that has been left out?
		5.4	Is there any capability you think should not be included?
		5.5	Among these capabilities, are there any you consider essential to classify a system as a control tower?
		5.6	Are there any of these capabilities that do not apply to your control tower?
6.0	Benefits and Challenges	6.1	Do you perceive any benefits in using a control tower? Which ones?
		6.2	Do you perceive any challenges in using a control tower? Which ones?
7.0	Final Considerations	7.1	Do you want to make any other comments?
		7.2	Can you suggest another experienced professional be interviewed?

Appendix C – CT's concept definition from practitioners' perspective

Practitioner	Practitioner's perspective
Respondent 1	Junction between operational and tactical teams, which will operate with the tools, and technologies that help in decision-making on certain productivity indicators. By uniting this, and being able to generate value from it in the chain, it becomes a control tower
Respondent 2	Centralized system for managing and monitoring logistics operations, designed to ensure greater visibility of the whole, efficiency in deliveries, supply chain decision-making and excellence in customer service
Respondent 3	24-hour monitoring tool for any process that can generate alerts
Respondent 4	Sector responsible for integrating all logistical ends, from production to delivery to the end customer. Having clarity of all information and real-time control, it serves as an aid in decision-making, giving visibility and ends up being an intermediary of actions to solve possible deviations and problems.
Respondent 5	Set of dashboards that will provide visibility into what you want to control.
Respondent 6	Monitor the process as a whole, from beginning to end and have the traceability to locate deviations and act to correct them.
Respondent 7	Information hub from the organization's systems that allows real-time and on-time monitoring of any process and that has people taking effective actions to resolve deviations
Respondent 8	Central that provides real-time information for the most accurate decision making possible for both the customer and the carriers. It helps to reduce costs, working in real-time and on time.
Respondent 9	Differential tools for decision-making and strategic management aimed at generating business value.
Respondent 10	The control tower concept is aligned with the idea of centralizing and integrating information and logistics operations in real-time. A control tower functions as the management core, enabling: Complete visibility: Monitor the entire supply chain, from product output to delivery to the customer, ensuring traceability and predictability. Agile decision-making: Anticipate problems and respond quickly to operational delays, failures, or deviations, based on consolidated data. Team integration: Connect different areas, such as transportation, inventory, and customer service, promoting alignment and synergy in actions. Use of technology: Lean on tracking, routing, performance analysis, and KPI tools to optimize operations and generate strategic insights. Proactivity: Not only react to problems, but also implement continuous improvements, using predictive analytics and historical data.
Respondent 11	A very important link these days for the supply chain area, we have process structuring, integrated technology, fast communication, data thus facilitating problem solving and mapping improvements for the future. The "engine" of the entire chain, where we "orchestrate" how it will be done, bringing better cost and service.
Respondent 12	A tool that allows me to monitor the operation. It allows me to act on deviations to serve my customer well. All this at a competitive cost.

Respondent 13	Bring real-time data visibility and use this real-time and historical data to feed back into the operation.
Respondent 14	Technological structure embedded in monitoring with a robust system that provides real-time information on any robust mapping process that is to be monitored.
Respondent 15	Tool that unites the company in favor of visibility and current status of the operation.
Respondent 16	It delivers your operation information centrally and in real-time, whatever the operation you want to monitor.
Respondent 17	The control tower is an intelligence cell that ensures that what was planned will happen as efficiently as possible. If I have any problem in the execution, I will be alerted by the tower to act on the deviation and learn from it in applications of continuous improvement plans. Based on people, processes and technology, it can be applied in any process.
Respondent 18	The Control Tower is a framework that presents itself in the form of an information hub (or intelligence center or integrator hub) based on technology, processes and people that will bring visibility and predictability to the process in focus.
Respondent 19	A digital hub that works as a command center that will control a defined scope - a process that has a beginning, middle and end (end-to-end) - in a centralized way in real-time. Sharing the planning with employees and monitoring to ensure the quality of the execution.

Appendix D – Practitioners' perspective about CT's capabilities framework

Practitioner	Practitioner's perspective
Respondent 1	I agree with the presented definitions.
Respondent 2	I partially agree with the presented definitions. I suggest mentioning risk management aspects in alerts, focusing more on security. In the decision support capability, I would highlight operational resilience and the accuracy of problem resolution as outcomes. For automation, I see productivity improvement as an important aspect. I also identify a fifth capability related to customer experience, which results from an optimized supply chain that positively impacts the customer.
Respondent 3	I agree with the definitions.
Respondent 4	I agree with the presented definitions. I believe there is no automatic decision-making, but there are automated tools that assist in the decision-making process.
Respondent 5	I partially agree with the presented definitions. I see alerts more as a decision-support tool rather than a capability and think they should be included under automation. Additionally, I believe visibility should be centralized.
Respondent 6	I agree with the presented definitions.
Respondent 7	I partially agree with the definitions. I would replace "data" with "the ability to visualize the operation in real-time" in the visibility definition. I believe visibility can be achieved through telemetry, trackers, or mobile apps. Alerts should include prioritization. I suggest adding data-driven decision-making to decision support and renaming it to dashboards and KPIs.
Respondent 8	I partially agree with the presented definitions. In visibility, I believe information should be real-time, as near real-time is not sufficient. In decision support, I consider electronic fences and Power BI to be the most commonly used tools. Automation, in my view, should be used for routing and handling alerts.
Respondent 9	I partially agree with the definitions. I believe visibility should focus on what is most critical for the business—what truly adds value. Alerts should be defined to ensure they are relevant to operations. I also think that people and their business knowledge should be considered a capability.
Respondent 10	I partially agree with the definitions. In my opinion, traceability should come before visibility, and automation needs to have a clear focus.
Respondent 11	I partially agree with the definitions. I would include people before visibility. In my view, visibility should help identify patterns, and alerts should incorporate process improvements.
Respondent 12	I agree with the presented definitions but would replace the term "alerts" with "triggers."
Respondent 13	I partially agree with the definitions. In visibility, I would add "historical data" after "near real-time." For alerts, I believe an escalation list and a decision tree should be included as scripts for handling alerts. In the decision support capability, I see predictive capabilities based on historical data as essential.

Respondent 14	I agree with the presented definitions, but I would place visibility as the last level.
Respondent 15	I agree with the definitions. I see the need to prioritize alerts and establish a decision matrix for each one. In my view, the number of alerts should depend on the operation.
Respondent 16	I agree with the presented definitions. Regarding visibility, I believe the control tower will generate a large amount of data, but it's essential to have clarity on which KPIs truly add value to the operation. Based on this, alerts should be configured to allow prioritization and rationalization according to the operation, making monitoring meaningful. I see a middle ground between visibility and alerts in defining what actions to take.
Respondent 17	I partially agree with the presented definitions. I would include an earlier capability, such as process standardization and work instructions. Beyond the framework, I believe achieving the fourth level depends on operational maturity and continuous investment in technology.
Respondent 18	I partially agree with the definitions. I don't see them as capabilities but rather as scopes of action. In my opinion, the supply chain tower should only include transportation planning. Once the vehicle arrives at the dock for loading, it should fall under the transportation tower until it reaches the final customer.
Respondent 19	I agree with the definitions but believe that visibility is linked to tracking data capture. Technologies such as GPS, RFID, and mobile apps provide visibility, but this alone is not enough. It's necessary to compare these "traces" with a standard. From this comparison, an automatic alert is triggered if something goes wrong—this is the essence of monitoring. However, alerts alone are not enough; there must be an escalation procedure (escalation list and decision tree) to address the issue. The final step is automation, which in the future will involve machine learning and AI, but currently, it focuses more on repetitive processes.
Respondent 20	I partially agree with the presented definitions. I think traceability should be included before visibility, and alerts should be part of visibility.
Respondent 21	I agree with the presented definitions. But I believe that alert prioritization should be added to it.

Appendix E – Respondents perspective about most common CT's definition framework

Respondent	Questions 4.1 to 4.4	Question 4.5
Respondent 1	I agree with the presented definitions.	I don't see other types of control towers.
Respondent 2	I agree with the presented definitions, but I believe the Inventory tower seems to be more aligned with a cross-chain tower. It might be worth making the definition more generic.	Safety control tower.
Respondent 3	I partially agree with the presented definitions. In my view, the supply chain tower should only include transportation planning. Once the vehicle arrives at the dock to load the planned material, it should fall under the transportation tower up to the final customer.	Customer service control tower (acting as a service provider to other companies), production control tower, logistics control tower (transport and inventory).
Respondent 4	I agree with the presented definitions.	I don't see other types of control towers.
Respondent 5	I agree with the presented definitions.	I don't see other types of control towers.
Respondent 6	I agree with the supply chain definition, but I believe the other towers could be considered as process-specific towers. I suggest defining them as "Management of a specific process," with examples such as transportation and inventory.	Production Control Tower.
Respondent 7	I agree with the presented definitions, but I would add delivery management to the definition of the supply chain tower.	Order management control tower and risk management control tower (safety and security).
Respondent 8	I agree with the presented definitions, but I think they are too summarized. In the transportation tower, I would include the identification of key issues and proactive corrective actions. In the inventory tower, I emphasize the importance of space optimization.	Safety control tower, which monitors speed, sudden braking, among other parameters of trucks, and helps reduce accidents.
Respondent 9	I agree with the presented definitions, but I find that being effectively online is challenging due to costs.	I don't see other types of control towers.
Respondent 10	I agree with the presented definitions.	Production Control Tower and an Inventory Control Tower to manage multiple DCs (viewing

		all SKUs in an integrated way) within the WMS.
Respondent 11	I agree with the presented definitions.	I don't see other types of control towers.
Respondent 12	I agree with the definitions, but I believe the core function of a control tower is deviation management, which is not clearly stated. I prefer the definition of the entire supply chain tower, as it provides a clearer purpose by emphasizing decision-making support.	Production Control Tower (Cutting, Loading, and Transshipment of sugarcane).
Respondent 13	I partially agree with the presented definitions. In my opinion, the control tower should provide data to support better fleet utilization planning. I see the supply chain control tower as the integration of several towers focused on specific processes.	Safety Control Tower. This CT can also impact the logistics chain if there is no way to track (without GPS mirroring and internal cameras, for example), which could prevent the trip. On the other hand, if I have the safety control tower but don't make decisions based on its data, it wouldn't have an impact.
Respondent 14	I partially agree with the presented definitions. I believe that in the transportation tower, the role of the people working in it is crucial to ensure its proper functioning.	Production Control Tower (Cutting, Loading, and Transshipment of sugarcane).
Respondent 15	I agree with the presented definitions, but I think the transportation tower is the most common. I have never seen an inventory tower as described. I consider.	Safety control tower (accidents) or risk management (cargo). The risk management control tower is the most traditional. Recently, safety control towers with ESG have also been emerging. Loading control tower (only seen at Unilever).
Respondent 16	I agree with the presented definitions. I believe that while three different towers can exist, it is also possible to have a single tower with three distinct operational cells.	Safety Control Tower.
Respondent 17	I agree with the presented definitions, but I would add continuous improvement to them. In my view, the order management function should be part of the supply chain tower.	Order control tower and safety control tower. The latter does not focus on productivity but adds value to the logistics operation, making the end of the line more efficient by preventing accidents.