1. Introduction

Sales and Operations Planning (S&OP) is a cross-functional business process aimed at harmonizing demand and supply over the medium term (THOMÉ et al., 2012) by establishing a systematic approach for vertical alignment of business strategy with operational execution, as well as horizontal alignment of demand and supply related plans (WAGNER et al., 2013). It enables organizations to anticipate and react more adeptly to shifting market dynamics (DANESE et al., 2017; GRIMSON & PYKE, 2007; KIM & SHIN, 2024). Despite its recognized value, many organizations continue to face significant challenges in fully leveraging S&OP (KREUTER et al., 2021). Research indicates that these difficulties often arise from the complexities of global supply chains, the rapid evolution of business environments, and inadequate or incomplete technology usage (JONSSON et al., 2021; KREUTER et al., 2022; KRISTENSEN & JONSSON, 2018). As companies grapple with increased volatility and uncertainty, their existing S&OP processes, frequently reliant on traditional methodologies and manual workflows, prove insufficient for meeting the demands of modern, fast-paced decision-making (DANESE et al., 2017; GRIMSON & PYKE, 2007; KALLA, SCAVARDA, & HELLINGRATH, 2025; KIM & SHIN, 2024; SAMOUCHE & EL KHALFI, 2023).

Recently, there has been a growing consensus on the need of integrating advanced technologies, such as big data analytics (BDA), advanced analytics, digital twins, artificial intelligence (AI), and machine learning (ML), into S&OP processes to enhance their effectiveness and agility (JONSSON et al., 2021; KALLA, SCAVARDA, & HELLINGRATH, 2025; SENGUPTA & DREYER, 2023; X. XU et al., 2021). These technologies align with the broader context of digital transformation and are fundamental to the principles of Industry 4.0 (I4.0) - (BAI et al., 2020). Characterized by the convergence of digital, physical, and biological systems through innovations like the Internet of Things (IoT), big data, AI, blockchain, and cloud computing, I4.0 is already revolutionizing various sectors (HOFMANN et al., 2019).

The integration of I4.0 technologies into S&OP is viewed as a critical enabler of enhanced agility, transparency, and decision-making (NICOLAS et al., 2021; SCHLEGEL et al., 2021). Jonsson et al. (2021) and Kalla, Scavarda, and Hellingrath (2025) emphasize that the incorporation of these technologies can enrich data insights and accelerate decision-making within S&OP. Bushueva and Afanasyev (2024) argue that digitalization and automation within S&OP can boost profitability by addressing complex management challenges, synchronizing processes, and enabling organizations to adapt more quickly to change. However, the practical adoption of I4.0 technologies in S&OP remains limited (ANTUNES et al., 2020; OHLSON, 2023). The slow adoption of these technologies can be attributed to several factors, including the absence of comprehensive frameworks that address the full spectrum of I4.0's capabilities and application areas within S&OP. While some studies have incorporated technology elements into maturity models (DANESE et al., 2017; GRIMSON & PYKE, 2007), these models primarily focus on technological readiness rather than the broader transformational potential of I4.0 in S&OP.

Research to date has not yet comprehensively addressed the integration of I4.0 technologies in S&OP (ANTUNES et al., 2020; BUSHUEVA & AFANASYEV, 2024). The intersection of these fields remains underexplored, with most studies focusing narrowly on specific technologies rather than examining a cohesive approach. Furthermore, the concept of "S&OP 4.0", an evolution of traditional S&OP enhanced by digital technologies, has yet to gain substantial traction in academic discourse, underscoring the gap in the literature and the need for deeper exploration into this integrated approach (KALLA, SCAVARDA, & CAIADO, 2025).

Addressing this gap, the goal of this study is to identify and analyze the I4.0 technologies applied in S&OP, integrating the fragment knowledge available in the academic literature by mapping their specific capabilities and contributions to the transition towards S&OP 4.0. By investigating these technologies, this research aims to bridge the divide between fragmented theoretical advancements in digital transformation and their practical application within a holistic view for S&OP. From a theoretical perspective, this study enhances the academic discourse by providing a structured synthesis of existing technologies and their roles in modern S&OP frameworks. From a practical standpoint, the findings offer actionable insights for organizations seeking to enhance decision-making, agility, and overall operational efficiency in their tactical planning processes. This leads to the formulation of the following research questions:

- Which I4.0 technologies can be effectively integrated into S&OP processes to achieve the transition to S&OP 4.0?
- What specific capabilities do these technologies possess that enhance S&OP operations?

By answering these research questions, this study contributes to the development of a comprehensive framework for integrating I4.0 technologies into S&OP. To achieve its goal, this paper adopts a methodological approach that combines a scoping review with an expert panel study. The scoping review systematically identifies I4.0 technologies and their capabilities in S&OP, ensuring a broad, comprehensive and integrative understanding of existing research, which is complemented by an expert panel, which validates and enriches the findings through industry insights from practitioners. This combined approach ensures both theoretical rigor and practical relevance, addressing the complexities of digital transformation within S&OP.

2 Theoretical Foundation

This section establishes the theoretical underpinnings of the study, beginning with an exploration of the I4.0 paradigm, including its defining technologies, followed by an analysis of the current state of S&OP and the role of digital technologies in its evolution.

2.1. Industry 4.0 Technologies

I4.0 has reshaped global industrial and business landscapes, compelling organizations to adopt advanced technologies to maintain competitiveness (GHOBAKHLOO, 2019; NASCIMENTO et al., 2019). It integrates smart manufacturing, IoT-enabled products, and data-driven decision-making, enabling real-time monitoring of production, machinery, and supply chain flows (CHAUHAN & SINGH, 2019; LASI et al., 2014). This integration empowers managers with unprecedented visibility and agility, facilitating proactive adjustments to operational disruptions (GHOBAKHLOO, 2019). To establish a comprehensive understanding of I4.0 technologies, this research employs a triangulation approach, integrating insights from three seminal studies. Zheng et al. (2021) offers an analysis of I4.0 applications in manufacturing environments, focusing on their operational implementation and performance outcomes. Complementing this technical view, Koh et al. (2019) examines the broader strategic implications of these technologies, particularly their transformative effects on supply chain operations and competitive dynamics. Tortorella et al. (2023) presents a critical practitioner-oriented perspective, identifying common implementation challenges and dispelling prevalent misconceptions about I4.0 adoption. The synthesis of these perspectives, as systematically presented in Table 1, includes a comprehensive listing of relevant technologies alongside detailed descriptions of their functionalities and applications.

Table 1 - Overview of Industry 4.0 Technologies

Technology	Description
3D Printing	A manufacturing process that creates physical objects layer by layer from digital designs.
5G	The 5th generation of mobile networks offering ultra-fast data speeds, low latency, and high device connectivity.
Additive Manufacturing	A broader term for 3D printing, referring to the process of building objects by adding material layer by layer.
Artificial Intelligence	The simulation of human intelligence by machines, enabling them to learn, reason, and make decisions.
Augmented Reality	Technology that overlays digital information onto the physical world through devices like smart glasses.
Automation	Use of machines and control systems to operate processes with minimal human intervention, increasing efficiency & consistency.
Big Data Analytics	The process of analyzing vast amounts of data to get patterns, trends, and insights, supporting smarter & faster decision-making.
Blockchain	A decentralized digital ledger that records transactions securely and transparently.
Cloud Technology	Delivers computing services (storage, processing, software) over the internet, enabling remote access, scalability, & collaboration.
ML	Subfields of AI where systems learn from data and improve performance over time.
Digital Twin	A virtual replica of a physical asset or system used for simulation, monitoring, and optimization.

IoT	Network of interconnected devices that collect and exchange data.
Remote Control	The ability to operate, control and monitor or observe machines and processes from a distance.
Robots	Machines capable of carrying out tasks autonomously or with human collaboration
Visualization	Tools and software that present complex data visually.

Source: Adapted from Zheng et al. (2020), Koh et al. (2019), Tortorella et al. (2023)

2.2. Technologies in S&OP

S&OP is a monthly, iterative process designed to produce integrated, profit-optimized plans through planning, review, and evaluation cycles (WAGNER et al., 2013). It has been extensively researched, resulting in a widely accepted five-step framework ((ÁVILA et al., 2019; HULTHÉN et al., 2016): Data Gathering (i), Demand Planning (ii), Supply Planning (iii), Pre-S&OP Meeting (iv), and Executive Meeting (v). However, current research indicates that the traditional Data Gathering step is no longer treated as an independent step. Instead, data integration is now embedded as a continuous capability throughout the S&OP process, reflecting the increasing role of real-time data and advanced analytics in modern S&OP frameworks (KALLA, SCAVARDA, & HELLINGRATH, 2025; KREUTER et al., 2021). Demand Planning involves marketing and sales teams jointly developing a consensus-based, unconstrained demand forecast covering 6 to 18 months. In Supply Planning, operations teams compare actual vs. planned performance, assess inventory, capacity, and lead times, and develop a rough-cut capacity plan (WAGNER et al., 2013). Pre-S&OP Meeting brings together cross-functional teams (e.g., sales, marketing, production, finance) to reconcile supply and demand plans. Scenario simulations are often performed here to explore alternative planning assumptions and evaluate trade-offs (HULTHÉN et al., 2016). These simulations support decision-making and result in an integrated plan proposal. In the Executive Meeting, senior management, together with the S&OP process owner, reviews the proposed plans, adjusts them if necessary, and ensures alignment with corporate goals. The finalized plan, along with critical KPIs and decisions, is then approved and communicated across the organization.

Traditional S&OP processes often rely on manual data handling and fragmented decision-making, limiting their agility in volatile markets (KALLA, SCAVARDA, & CAIADO, 2025; KRISTENSEN & JONSSON, 2018; NICOLAS et al., 2021). In response, technology has emerged as a key enabler of agile and data-driven S&OP, supporting real-time integration, predictive analytics, and collaborative planning (DANESE et al., 2017; NETO et al., 2022). Many maturity models emphasize technology as a core element, with advanced systems marking higher levels of digital readiness (BELOTTI et al., 2017). However, current research is fragmented, often focusing on isolated tools or cases. A comprehensive framework linking Industry 4.0 technologies to S&OP

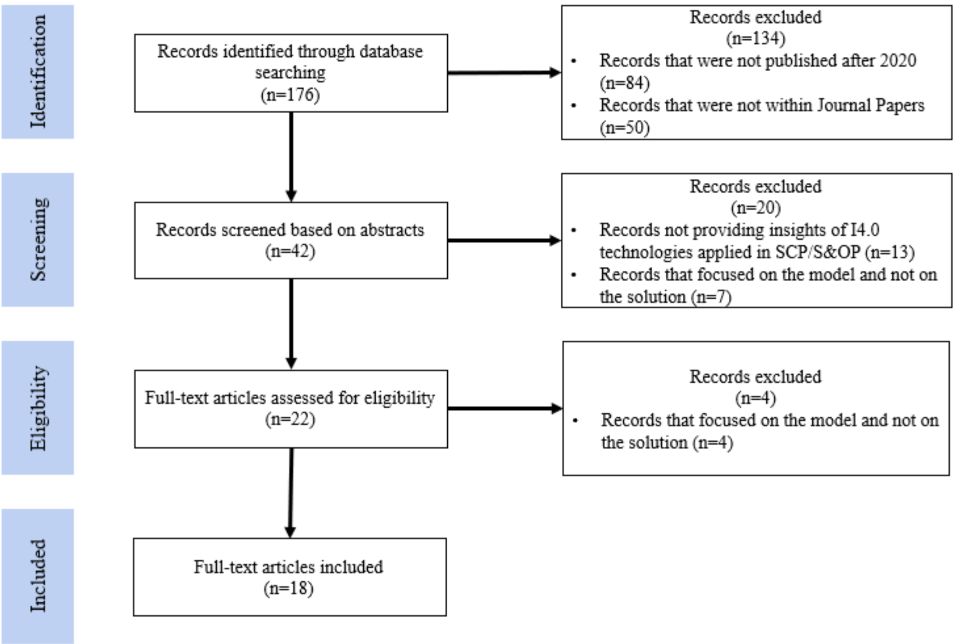
performance dimensions, such as agility, visibility, and responsiveness, remains lacking (KALLA, SCAVARDA, & CAIADO, 2025).

3. Methodology

This study adopts a mixed-methods approach combining a scoping literature review with an expert panel study. By triangulating academic and practitioner perspectives, it ensures both theoretical rigor and practical relevance in examining how I4.0 technologies can be integrated into S&OP.

A scoping review was chosen due to the broad and interdisciplinary nature of the topic. It allows exploratory inquiry and the inclusion of diverse study types, making them suitable for mapping fragmented or emerging fields as I4.0 in S&OP (ARKSEY & O'MALLEY, 2005; ARMSTRONG et al., 2011). This review follows Arksey and O'Malley's five-stage framework and is reported using PRISMA guidelines (MOHER et al., 2009) for transparency, as shown in Figure 1.

Figure 1 – Papers retrieved from the PRISMA perspective



Source: Adapted from Moher et al. (2009)

The research questions guiding the review focus on identifying which I4.0 technologies are applied within S&OP, how these technologies contribute to performance improvement, and where research gaps remain. To identify relevant literature, the Scopus database was selected due to its broad and multidisciplinary coverage of high-quality, peer-reviewed journals in operations, supply chain management, and information systems (PEDROSO et al., 2016). A comprehensive search string was developed, combining terms related to S&OP and adjacent domains—such as "Sales and Operations Planning," "S&OP," "Supply Chain Planning," and "Supply Chain Execution"—with a curated list of I4.0 technologies, as outlined in Table 1. This search string was inspired by previous literature in the field, including Thomé et al. (2012), Kreuter et al. (2021), and Kalla, Scavarda, and Hellingrath (2025). The initial search, conducted on April 2, 2024, yielded 176 results. To ensure relevance and quality, two filters were applied: publication years 2020–2025 and journal articles only, reducing the sample to 42. Three researchers then independently screened titles, abstracts, and full texts. Articles were excluded if they focused solely on technical algorithmic improvements (n=7) or lacked any I4.0 connection (n=13). After resolving disagreements through consensus, 22 articles were selected for full-text review. Four additional studies were excluded for again lacking a clear link between technology and S&OP capabilities. The final sample consisted of 18 peer-reviewed journal articles forming the core dataset.

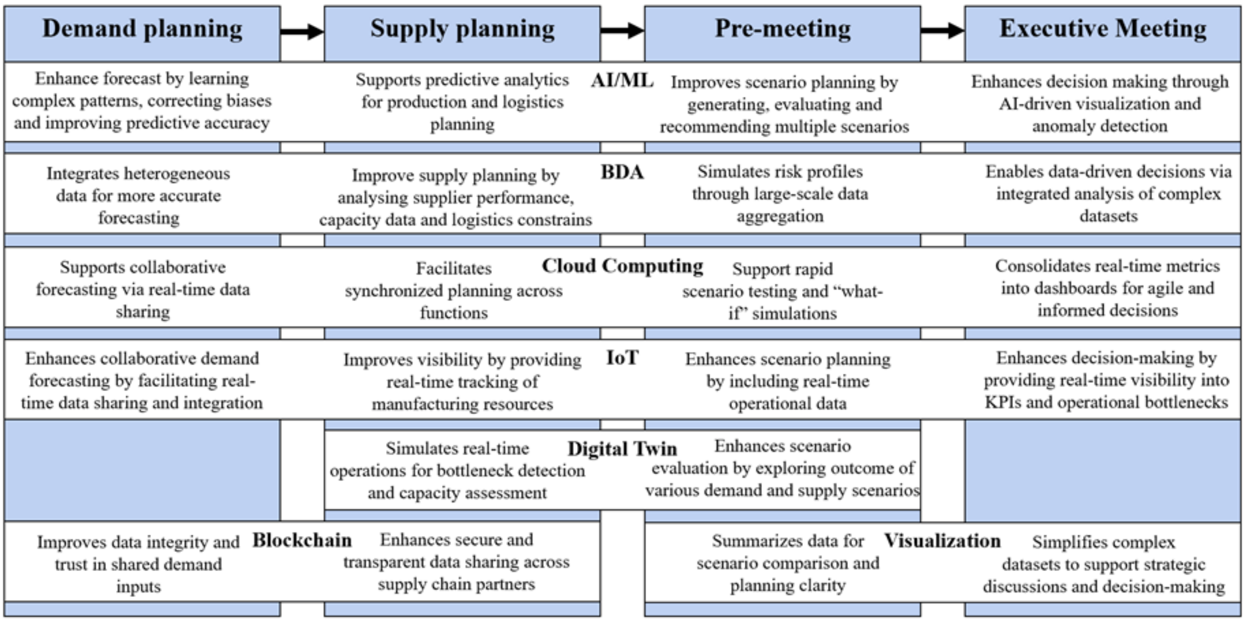
To validate and enrich the findings from the scoping review, semi-structured expert interviews were conducted. Three experts participated, all with academic backgrounds and practical experience in S&OP or related supply chain domains. Each interview lasted approximately one hour. The sessions began with a brief introduction to the S&OP process and relevant I4.0 technologies, followed by a presentation of the preliminary framework developed from the literature. Experts were then asked to evaluate the framework's alignment with real-world practice and suggest any additions, adjustments, or removals of capabilities at specific S&OP steps. After each interview, the framework was refined based on the feedback before being discussed in the subsequent session, enabling an iterative and cumulative validation process.

4. Results

This section presents the research findings, outlining which I4.0 technologies are applied within the S&OP process and highlighting their capabilities. The scoping review revealed that the majority of studies offer valuable insights on the application of AI and ML, with eight studies focusing on their role in enhancing forecasting accuracy and decision-making. BDA also emerged as a central theme, discussed in four studies for its potential to support data integration, scenario analysis, and dynamic planning. In addition to these, the review identified relevant contributions on Digital Twins, IoT, Blockchain, Cloud Computing, and Visualization Tools, each offering distinct support across different S&OP steps. Experts confirmed the review findings from these technologies. Other I4.0 technologies, such as 3D Printing, Additive Manufacturing, 5G, Augmented Reality, Automation, Remote Control, and Robotics, were absence in the academic literature. Expert insights offered additional justification for their exclusion. Specifically, technologies like 3D Printing, Additive Manufacturing, Automation, Remote Control, and Robotics are largely focused on manufacturing operations and offer limited direct benefits to planning tasks. Regarding 5G, Expert 2 noted that it should be viewed more as an enabler of high-speed connectivity, especially for IoT applications, rather than a technology that can be directly implemented in planning activities. Robotic Process Automation (RPA) was also mentioned by Expert 2 as potentially useful for automating scenario analyses or aligning supply and demand. However, since RPA is primarily focused on improving process efficiency rather than directly enhancing planning quality, its exclusion from a planning-focused framework is justifiable. Overall, the limited planning relevance of these technologies may explain their absence in the academic literature and further supports their exclusion from the proposed S&OP 4.0 framework.

Building upon the research findings, a S&OP 4.0 framework is developed (Figure 2), which maps the main capabilities of each identified technology to the core steps of the S&OP process: Demand Planning, Supply Planning, Pre-Meeting, and Executive Meeting.

Figure 2 – S&OP 4.0 framework



While most I4.0 technologies offer potential benefits across the entire S&OP process, this study adopts a step-specific mapping approach to reflect the dominant application context of each technology. This decision is guided by the principle of technology-process fit (GOODHUE & THOMPSON, 1995), which suggests that technologies deliver the highest value when aligned with the specific informational and functional requirements of a given task. Accordingly, technologies were assigned to the S&OP steps where their capabilities most strongly match the step's needs, based on a synthesis of academic literature and expert insights. Such approach ensures analytical clarity and avoids overstating the ubiquity of technological applications.

AI and ML are the most frequently discussed technologies, with the literature highlighting their transformative potential for S&OP. Their impact is particularly significant in the Demand Planning step, enabling advanced capabilities such as pattern recognition, bias correction, and anomaly detection in historical sales and market data (KHLIE et al., 2024; MBONYINSHUTI et al., 2022; MELANÇON et al., 2021; PANWAR et al., 2022; SANKARAN et al., 2024; VLACHOS & REDDY, 2025). Several studies emphasize the critical role of ML in improving forecast accuracy by learning from complex demand patterns and historical trends (PATTNAIK et al., 2024; PAULL et al., 2025; SCHLEGEL et al., 2021). In the context of Supply Planning, AI supports predictive analytics and the optimization of production and logistics decisions. For instance, Bodendorf et al. (2023) and Paull et al. (2025) illustrate how AI-driven systems can anticipate supply disruptions and enhance production planning trough predictive analytics. In the Pre-Meeting step, AI contributes by facilitating scenario modeling and simulation. As highlighted by Expert 1, AI systems are capable of generating, assessing, and recommending planning alternatives, thereby enabling decision-makers to evaluate the potential impact of different strategies under varying conditions. During Executive Meetings, AI can be integrated into advanced visualization systems that assist in interpreting complex datasets. These systems enhance the decision-making process by highlighting critical patterns, trends, and anomalies, thus making discussions more evidence-based and actionable (DOLGUI & IVANOV, 2025). Expert 1 confirmed the strong industrial relevance of AI in Demand Planning, noting its growing adoption due to the direct and measurable benefits it provides. However, he also observed that AI's application in the remaining S&OP steps remains limited in practice. While its potential in these stages is widely acknowledged, the actual implementation often falls short, suggesting a gap between technological capability and organizational readiness or resource availability. Jazairy et al. (2024) investigate this issue in greater depth, highlighting key paradoxes in AI adoption within S&OP, as the trade-off between achieving short-term efficiency using existing tools and waiting for full AI maturity. These paradoxes may help explain the relatively slow and uneven adoption of AI in S&OP.

The application of **BDA** is also evident across all stages of the S&OP process. The scoping review and interviews revealed its prominent role in enhancing forecasting accuracy by integrating large and heterogeneous data sources. Studies such as J. Xu and Pero (2023) demonstrated that BDA can improve demand prediction through the analysis of historical, behavioral, and contextual data. Dolgui and Ivanov (2025) further emphasize the added value of incorporating external sources, such as customer activity and market signals, into the forecasting process. In the context of Supply Planning, BDA supports the development of dynamic capabilities by facilitating real-time assessments of supplier reliability, capacity constraints, and logistics performance, as discussed by Pattnaik et al. (2024) and corroborated by Expert 1. Expert 2 also underscores the importance of integration in this context, noting that BDA facilitates the breakdown of data silos and provides a more secure and comprehensive approach to evaluating supply-side data. During the Pre-

Meeting step, BDA can support scenario simulation by aggregating and analyzing large-scale data to identify potential outcomes and risk profiles, which helps improve the quality of preparatory planning (SCHLEGEL et al., 2021). At the Executive Meeting, BDA enables decision-makers to derive integrated insights from complex and heterogeneous datasets, thereby facilitating more informed, agile, and data-driven decision-making processes, as emphasized by Expert 1. However, Expert 1 also noted that despite its potential, the practical implementation of BDA in industry remains limited. He underscored that its application across all S&OP levels is often perceived as too resource-intensive and costly, which hinders widespread adoption.

Cloud Computing emerged as a critical enabler of collaboration, integration, and scalability within the S&OP process. Gahm (2020) proposed a conceptual framework for cloud-based advanced planning systems that demonstrates significant relevance for S&OP. This framework highlights how cloud-based planning systems can facilitate the cross-functional and cross-organizational collaboration that is widely recognized as a key success factor in S&OP (DANESE et al., 2017). As emphasized by Gahm (2020) and Expert 1, cloud computing enhances collaborative demand forecasting by enabling real-time data sharing between internal departments and external supply chain partners. This fosters alignment across stakeholders and improves the responsiveness and accuracy of demand plans (Expert 1). In the Supply Planning step, cloud-based systems support the co-creation of synchronized plans by providing seamless access to shared data and applications. This capability enhances organizational agility and enables coordinated planning efforts across functional silos (Expert 3). During the Pre-Meeting step, the cloud environments support the execution of rapid "what-if" simulations and scenario testing, thereby improving the speed and depth of preparatory analysis (Expert 2). In Executive Meetings, cloud infrastructure underpins integrated dashboards that consolidate operational and strategic metrics in real-time, enabling decision-makers to access up-to-date insights and make informed, data-driven decisions (GAHM, 2020). Moreover, Expert 2 underscored the broader value of cloud computing across all S&OP steps. In addition to supporting data standardization and ensuring security, cloud platforms also simplify the deployment of AI and BDA applications by offering scalable computing resources and centralized data integration.

The **IoT** was identified as a foundational enabler of real-time operational visibility, enhancing responsiveness and data accuracy across all stages of the S&OP process. He et al. (2020) provide valuable insights into how IoT, when integrated with big data services, supports supply chain planning and coordination by generating continuous data streams from physical assets. Overall, IoT technologies enrich the S&OP process by supplying high-frequency, real-world data that can be leveraged throughout its different steps. In Demand Planning, IoT devices capture granular information on product usage, customer behavior, and inventory movements (HE et al., 2020), thereby supplying more precise and context-rich inputs for demand forecasting models. Expert 2 emphasized the ability of IoT to monitor operations in real-time, enabling early identification and prevention of bottlenecks, which improves forecast reliability and planning agility. Within Supply Planning, IoT facilitates dynamic and data-driven resource allocation by monitoring real-time machine availability, production status, and stock levels. According to Expert 1, IoT plays a particularly important role in enhancing inventory management through improved visibility, traceability, and control over material flows. During the Pre-Meeting step, real-time data collected from IoT sensors can strengthen scenario planning by grounding simulations in current operational realities (Expert 2). These same data streams also contribute to more informed Executive Meetings by offering decision-makers immediate access to key performance indicators, disruptions, and supply chain anomalies. This enables faster, evidence-based interventions and more agile strategic responses (Expert 1).

The scoping review and expert interviews highlight a growing interest in the application of **Digital Twin** technologies within the S&OP process, particularly in the areas of Supply Planning and scenario simulation. Sengupta and Dreyer (2023) examine the sustainability implications of Digital Twin–driven S&OP and provide valuable insights into how this technology can be embedded in planning environments. Digital Twins generate dynamic, virtual representations of physical supply chains and associated planning processes, enabling practitioners to simulate and evaluate alternative strategies within a controlled, risk-free setting (DOLGUI & IVANOV, 2025). In the Supply Planning step, this technology allows for the real-time simulation of operations, supporting the identification of bottlenecks, assessment of capacity constraints, and optimization of resource allocation (SENGUPTA & DREYER, 2023). According to Expert 1, in the Pre-Meeting step, Digital Twins play a critical role in validating planning assumptions by supporting data-driven scenario exploration.

Blockchain technology has also been identified as a relevant I4.0 technology within the context of S&OP. Rahmanzadeh et al. (2020) propose a blockchain-based registration mechanism through which ideas and creative inputs are collected, refined, and formally validated within supply chain tactical planning. In this context, blockchain can offer the potential to ensure secure, transparent, and immutable information exchange across the supply network. Both Expert 1 and Expert 2 emphasized the governance and compliance benefits of blockchain, particularly in the Demand Planning and Supply Planning steps. They noted that decentralized verification mechanisms support data integrity, reduce the risk of manipulation, and foster greater trust among supply chain partners. This enhanced transparency enables more reliable and coordinated planning, especially in global, multi-tiered supply networks where data validation across entities is critical. However, both experts also acknowledged that blockchain adoption in S&OP remains limited. High implementation costs, technological complexity, and the relative novelty of its application in planning contexts pose significant barriers. As a result, while the potential of blockchain is widely recognized, its current use in S&OP is still in an early and experimental stage.

Visualization technology is mainly used within S&OP for transforming complex data into accessible insights. As previously discussed, AI-enhanced visualizations are particularly valuable in the Executive Meeting step, simplifying data environments and supporting strategic decisions (DOLGUI & IVANOV, 2025). According to Expert 1, although visualization tools are most prominent at the executive level, they can also support the Pre-Meeting step by summarizing complex datasets and enabling scenario comparisons. Expert 2 adds that it improves usability and provides clearer views of planning data. While applicable across the entire S&OP process, Expert 3 justified including this technology in the framework only for the Pre-Meeting and Executive Meeting steps. These are the steps where clear communication and shared understanding are most critical, and where visualization adds the greatest value for decision-makers.

5. Conclusions

This research has systematically examined the integration of I4.0 technologies into the S&OP process, addressing a critical gap in the literature by developing an S&OP 4.0 framework. This framework maps the capabilities of advanced technologies across the four core S&OP steps. The Technologies AI, ML, BDA, Blockchain, Cloud Computing, IoT, Digital Twins, and Visualization Tools were identified as key enablers that support enhanced forecasting accuracy, scenario modeling, supply chain transparency, cross-functional collaboration, and strategic decision-making. Among these technologies, AI and ML emerged as particularly impactful in the Demand Planning step due to their ability to detect patterns and mitigate forecast biases, enabling more data-driven decisions. BDA supports large-scale data integration and facilitates dynamic planning. Cloud Computing enhances cross-functional alignment by enabling real-time collaboration through shared platforms. IoT and Digital Twins contribute real-time operational data and simulation capabilities that allow for responsive and adaptive planning. Blockchain has the potential to improve trust and traceability in supply planning, although its practical adoption remains limited. Visualization technologies play a vital role in Supply Planning and Executive Meetings by simplifying complex data and enabling evidence-based decision-making.

A significant limitation identified in the academic discourse is that most studies included in the scoping review take a broad SCP perspective, often providing only high-level insights without delving into how these technologies are concretely applied within the specific S&OP context. Technologies like Digital Twins, IoT, and Blockchain were discussed in only a few papers, yielding limited insights. In contrast, AI and ML dominated the literature, receiving the most attention and detailed examination. Moreover, practical adoption of some technologies remains limited. Aside from AI, Cloud Computing, and Visualization Tools, most I4.0 technologies are not widely implemented in S&OP environments. Expert insights revealed that barriers such as technological immaturity, high implementation costs, and organizational resistance contribute to the slow uptake. These findings suggest a disconnect between theoretical potential and practical readiness. To address this gap, future research should further explore the “people” and “process” dimensions of technology adoption. Understanding how organizational structure, digital culture, and employee openness affect adoption could explain both the scarcity of concrete implementation studies in the literature and the observed low adoption in practice.

This paper contributes to both academic and practical domains. For academia, it offers a foundational framework and proposes avenues for future research, including in-depth empirical studies and longitudinal assessments. For practitioners, it provides actionable insights into how specific technologies can enhance forecasting accuracy, improve collaboration, and foster more resilient and agile S&OP processes. By bridging the gap between theoretical frameworks and operational realities, this research lays the foundation for a more intelligent, adaptive, and digitally enabled approach to S&OP, referred to here as S&OP 4.0. Fully realizing this vision, however, requires not only continued technological innovation but also a concerted focus on organizational transformation and the development of an expanded, evidence-based research agenda.

Acknowledgments

The authors of this paper would like to express their gratitude to the three experts involved in the panel and to the following Brazilian research funding agencies: CAPES, CNPq, and FAPERJ.

References

Antunes, S., Okano, M., & Ribeiro, R. (2020). Sales and Operations Planning (S&OP) and Digital Transformation: A Narrative Review. *Research, Society and Development*, *9*, e746986506.

Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology*, *8*(1), 19–32.

Armstrong, R., Burford, B., Doyle, J., & Waters, E. (2011). ‘Scoping the scope’ of a Cochrane review. *Journal of Public Health*, *33*, 147.

Ávila, P., Lima, D., Moreira, D., Pires, A., & Bastos, J. (2019). Design of a Sales and Operations Planning (S&OP) process – case study. *Procedia CIRP*, *81*, 1382–1387. 8

Bai, C., Dallasega, P., Orzes, G., & Sarkis, J. (2020). Industry 4.0 technologies assessment: A sustainability perspective. *International Journal of Production Economics*, *229*, 107776.

Belotti, C., Calache, L., Lima Junior, F. R., Da Silva, A., & Carpinetti, L. (2017). Proposal of a model for sales and operations planning (S&OP) maturity evaluation. *Production*, *27*, 1–17.

Bodendorf, F., Dentler, S., & Franke, J. (2023). Digitally enabled supply chain integration through business and process analytics. *Industrial Marketing Management*, *114*, 14–31.

Bushueva, L. I., & Afanasyev, V. B. (2024). Management of digital transformation of the sales and operations planning process in an organization. *КОРПОРАТИВНОЕ УПРАВЛЕНИЕ И ИННОВАЦИОННОЕ РАЗВИТИЕ ЭКОНОМИКИ СЕВЕРА*(4), 1–12.

Chauhan, C., & Singh, A. (2019). A Review of Industry 4.0 in Supply Chain Management Studies. *Journal of Manufacturing Technology Management*, *31*, 863–886.

Danese, P., Molinaro, M., & Romano, P. (2017). Managing evolutionary paths in Sales and Operations Planning: key dimensions and sequences of implementation. *International Journal of Production Research*, *56*, 1–18.

Dolgui, A., & Ivanov, D. (2025). Internet of behaviors: conceptual model, practical and theoretical implications for supply chain and operations management. *International Journal of Production Research*, *63*(1), 1–8.

Gahm, C. (2020). A conceptual framework for cloud-based advanced planning systems. *Journal of Decision Systems*, *32*, 1–30.

Ghobakhloo, M. (2019). Industry 4.0, Digitization, and Opportunities for Sustainability. *Journal of Cleaner Production*, *252*, 119869.

Goodhue, D. L., & Thompson, R. L. (1995). Task-Technology Fit and Individual Performance. *MIS Quarterly*, *19*(2), 213–236.

Grimson, J., & Pyke, D. (2007). Sales and operations planning: An exploratory study and framework. *The International Journal of Logistics Management*, *18*, 322–346.

He, L., Xue, M., & Gu, B. (2020). Internet-of-things enabled supply chain planning and coordination with big data services: Certain theoretic implications. *Journal of Management Science and Engineering*, *5*(1), 1–22.

Hofmann, E., Sternberg, H., Chen, H., Pflaum, A., & Prockl, G. (2019). Supply Chain Management and Industry 4.0: Conducting Research in the Digital Age. *International Journal of Physical Distribution & Logistics Management*, *49*, 945–955.

Hulthén, H., Naslund, D., & Norrman, A. (2016). Framework for measuring performance of the sales and operations planning process. *International Journal of Physical Distribution & Logistics Management*, *46*, 809–835.

Jazairy, A., Shurrab, H., & Chedid, F. (2024). Impact pathways: walking a tightrope-unveiling the paradoxes of adopting artificial intelligence (AI) in sales and operations planning. *International Journal of Operations & Production Management*, *45*, 1–27.

Jonsson, P., Kaipia, R., & barratt, m. (2021). Guest editorial The future of S&OP: dynamic complexity, ecosystems and resilience. *International Journal of Physical Distribution & Logistics Management*, *56*, 553–565.

Kalla, C., Scavarda, L. F., & Caiado, R. (2025). Adapting sales and operations planning to dynamic and complex supply chains. *Review of Managerial Science.* Advance online publication.

Kalla, C., Scavarda, L. F., & Hellingrath, B. (2025). Integrating supply chain risk management activities into sales and operations planning. *Review of Managerial Science*, *19*(2), 467–497.

Khlie, K., Benmamoun, Z., Jebbor, I., & Serrou, D. (2024). Generative AI for enhanced operations and supply chain management. *Journal of Infrastructure, Policy and Development*, *8*, 6637.

Kim, S., & Shin, K. (2024). Comparative Analysis of Key Success Factors in S&OP: Focusing on Manufacturing and Retail Industry in South Korea. *Systems*, *12*(6).

Koh, L., Orzes, G., & Jia, F. (2019). The fourth industrial revolution (Industry 4.0): technologies disruption on operations and supply chain management. *International Journal of Operations & Production Management*, *39*(6/7/8), 817–828.

Kreuter, T., Kalla, C., Scavarda, L., Thomé, A. M., & Hellingrath, B. (2021). Developing and implementing contextualised S&OP designs – an enterprise architecture management approach. *International Journal of Physical Distribution & Logistics Management*, *51*, 634–655.

Kreuter, T., Scavarda, L. F., Thomé, A. M. T., Hellingrath, B., & Seeling, M. X. (2022). Empirical and theoretical perspectives in sales and operations planning. *Review of Managerial Science*, *16*(2), 319–354.

Kristensen, J., & Jonsson, P. (2018). Context-based sales and operations planning (S&OP) research: A literature review and future agenda. *International Journal of Physical Distribution & Logistics Management*, *48*, 19-46.

Lasi, H., Fettke, P., Kemper, H.-G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business &*

Information Systems Engineering, *6*(4), 239–242. 4

Mbonyinshuti, F., Nkurunziza, J., Niyobuhungiro, J., & Kayitare, E. (2022). The Prediction of Essential Medicines Demand: A Machine Learning Approach Using Consumption Data in Rwanda. *Processes*, *10*(10), 26–39.

Melançon, G., Grangier, P., Prescott-Gagnon, E., Sabourin, E., & Rousseau, L.-M. (2021). A Machine Learning-Based System for Predicting Service-Level Failures in Supply Chains. *INFORMS Journal on Applied Analytics*, *51*, 200–212. https://doi.org/10.1287/inte.2020.1055

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine*, *6*(7), e1000097.

Nascimento, D. L. M., Alencastro, V., Quelhas, O. L. G., Caiado, R. G. G., Garza-Reyes, J. A., Rocha-Lona, L., & Tortorella, G. (2019). Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context. *Journal of Manufacturing Technology Management*, *30*(3), 607–627.

Neto, J., Barcellos, P. F. P., & Panizzon, M. (2022). Beyond S&OP Implementation: A maturity model and meta-framework for assessing and managing evolution paths. *Brazilian Journal of Operations & Production Management*, *19*(3), 1–23.

Nicolas, F., Thomé, A. M., & Hellingrath, B. (2021). Usage of Information Technology and Business Analytics within Sales and Operations Planning: A Systematic Literature Review. *Brazilian Journal of Operations & Production Management*, *18*, e20211152.

Ohlson, N.-E. (2023). *Towards enhanced sales and operations planning : Using machine learning for decision support in an engineer-to-order context: Jth Dissertation Series* (087) [Licentiate thesis, comprehensive summary, Jönköping University, School of Engineering, Jönköping]. RIS.

Panwar, R., Pinkse, J., & Marchi, V. de (2022). The Future of Global Supply Chains in a Post-COVID-19 World. *California Management Review*, *64*(2), 5–23.

Pattnaik, S., Liew, N., Kures, A., Pinsky, E., & Park, K. (2024). Catalyzing Supply Chain Evolution: A Comprehensive Examination of Artificial Intelligence Integration in Supply Chain Management. *Engineering Proceedings*(68), 57–66.

Paull, S., Bubak, R., & Stuckenschmidt, H. (2025). Machine Learning for Master Production Scheduling: Combining probabilistic forecasting with stochastic optimisation. *Expert Systems with Applications*, *271*, 126586.

Pedroso, C. B., Da Silva, A. L., & Tate, W. L. (2016). Sales and Operations Planning (S&OP): Insights from a multi-case study of Brazilian Organizations. *International Journal of Production Economics*, *182*, 213–229.

Rahmanzadeh, S., Pishvaee, M. S., & and Rasouli, M. R. (2020). Integrated innovative product design and supply chain tactical planning within a blockchain platform. *International Journal of Production Research*, *58*(7), 2242–2262. https://doi.org/10.1080/00207543.2019.1651947

Samouche, H., & El Khalfi, A. (2023). Improving Alignment Between Supply and Demand Through The Analysis of Sales and Operations Planning (S&OP). *International Journal of Industrial Engineering*, *34*, 1–14.

Sankaran, G., Palomino, M. A., Knahl, M., & Siestrup, G. (2024). Towards a System Dynamics Framework for Human–Machine Learning Decisions: A Case Study of New York Citi Bike. *Applied Sciences*, *14*(22), 1–31.

Schlegel, A., Birkel, H., & Hartmann, E. (2021). Enabling integrated business planning through big data analytics: a case study on sales and operations planning. *International Journal of Physical Distribution & Logistics Management*, *ahead-of-print.*

Sengupta, S., & Dreyer, H. (2023). Realizing zero-waste value chains through digital twin-driven S&OP: A case of grocery retail. *Computers in Industry*, *148*, 103890.

Thomé, A. M., Scavarda, L., Suclla Fernandez, N., & Scavarda, A. (2012). Sales and operations planning: A research synthesis. *International Journal of Production Economics*, *138*, 1–13.

Tortorella, G. L., Saurin, T. A., Hines, P., Antony, J., & Samson, D. (2023). Myths and facts of industry 4.0. *International Journal of Production Economics*, *255*, 108660.

Vlachos, I., & Reddy, P. G. (2025). Machine learning in supply chain management: systematic literature review and future research agenda. *International Journal of Production Research*, 1–30.

Wagner, S., Ullrich, K., & Transchel, S. (2013). The game plan for aligning the organization. *Business Horizons*, *57*, 189–201.

Xu, J., & Pero, M. E. P. (2023). A resource orchestration perspective of organizational big data analytics adoption: evidence from supply chain planning. *International Journal of Physical Distribution & Logistics Management*, *53*(11), 71–97.

Xu, X., Lu, Y., Vogel-Heuser, B., & Wang, L. (2021). Industry 4.0 and Industry 5.0-Inception, conception and perception. *Journal of Manufacturing Systems*, *61*, 530–535.

Zheng, T., Ardolino, M., Bacchetti, A., & and Perona, M. (2021). The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review. *International Journal of Production Research*, *59*(6), 1922–1954.