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Advances in Supply Chain Optimization and Intelligent Business Analysis: A Conceptual Review

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Abstract- ***Advanced technology has transformed the concept of supply chain management and how companies are able to leverage data to gain insight into their business. The modern supply chain presents a number of new complexities, volatility and competition and needs intelligent systems to analyse, adapt and respond to situations in real-time, while being able to resist disruption. This conceptual overview investigates progress in the areas of Supply Chain optimization and Intelligent Business analysis, and aims to bring together the emerging global research stream of the six thematic areas of Artificial Intelligence and machine learning, Big Data analytics, Internet of Things, Predictive and Prescriptive analytics, Digital Twin technologies and Resilience and Disruption intelligence. The review was carried out by systematically searching the databases like Scopus, Web of Science, Google Scholar and other databases using the keywords: Supply chain optimization, Intelligent business analysis, Machine learning in supply chains, and Digital twin logistics with the period of the publications mostly from 2020 to 2024, and the articles were selected after the peer review process. The thematic analysis shows high consistency across the themes on how AI-based analytics and data-based systems can impact supply chain performance, and significant gaps in cross-functional integration, human-machine interactions and implementation in new economy contexts. A novel Intelligent Supply Chain Optimization Framework (ISCOF) is proposed to understand the layered relationship between the theoretical foundations, technological enablers and strategic outcomes. The review not only consolidates the theory by combining a vast number of non-related publications under one conceptual framework, but also offers some ideas and practical recommendations for the managers interested in introducing intelligent systems in the supply chain.***

Keywords: supply chain optimization; intelligent business analytics; artificial intelligence; big data analytics; internet of things (iot); digital twin technology; supply chain resilience.

I. INTRODUCTION

The 21st century has seen a dramatic shift in supply chain management (SCM) in the face of the rise of digital technologies, the growing volume of available data, and increasing disruptions around the world. Due to continued vulnerabilities in traditional supply chain designs caused by the COVID-19 pandemic, the geopolitical situation and the quickening changes in consumer behaviour, there is increasing demand for intelligent, responsive, and resilient operations (Toorajipour et al., 2021). In this background, the optimization of the supply chain and the intelligent analysis of business have become key elements of competitiveness, giving companies the ability to predict demand, control risk, and manage complex and multi-level supply chains with unprecedented precision. Although recent research and business interest is in this field, the current literature lacks a coherent approach that ties together the various disciplines (operations research, information systems, management science and data analytics) and spans the links between technology developments and supply chain results. Most previous studies have been conducted on specific technology or specific thematic areas, creating a lack of a comprehensive understanding of intelligent systems working together to make the supply chain's performance exemplary (Talwar et al., 2021).

To fill this gap, this review examines the progress in six key aspects and present a synthesis conceptual model. This review has three objectives: (1) to summarise and critically review the state of the art of the optimization of the supply chain and intelligent business analysis; (2) to identify common themes, controversies and gaps in the research; and (3) to define a research agenda for informing academic research and management practice. The review includes conceptual background, thematic literature

review, a proposed framework, discussion, research gaps, recommendations and conclusions.

II. CONCEPTUAL BACKGROUND AND THEORETICAL UNDERPINNINGS

Optimization of supply chain networks through analytical tools, algorithms and technologies in procurement, production, inventory management, logistics and demand fulfillment (Toorajipour et al., 2021). Intelligent Business Analysis, on the other hand, is the use of sophisticated data analytics, AI and decision support systems which help to transform structured and unstructured data from business and arrive at actionable insights for evidence-based decision making at Strategic, Tactical and Operational level (Talwar et al. 2021). Other constructs related to the resilience of supply chains are the ability to anticipate, adapt to and recover from disruptions (supply chain resilience) and various tools and processes to transform data into organisational knowledge (business intelligence).

There are several theoretical frameworks which support scholarship in this area. The Resource-Based View (RBV) theory suggests that firms can achieve competitive advantage by leveraging their valuable, rare, non-substitutable, and inimitable resources, thus, data and analytical capabilities represent strategic resources for the firm (Chowdhury et al., 2019). The Dynamic Capabilities Theory (DCT) developed by Teece et al. (1997) and extended in the studies of supply chain resilience, states that organizations' capacity to sense, seize and reconfigure resources is the basis of their adapting to uncertainty. While the first helps us understand supply chain as a complex adaptive system where technology and humans work in their dynamic intensity, the latter sheds light on the internalization/outsourcing choice of supply chain functions in the age of digital platforms. This review is different from previous conceptual reviews which have examined a single technology or a single theoretical framework because it brings together several theoretical perspectives within a single frame of the technology adoption, organisational capability and performance outcomes.

III. THEMATIC REVIEW OF LITERATURE

3.1 Artificial Intelligence and Machine Learning in Supply Chain Optimization

Artificial intelligence (AI) and machine learning (ML) have transformed the way to optimize supply chain. Toorajipour et al. (2021) presented a systematic review of the use of ML in different areas of the logistics, marketing, and production processes, and showed that ML technology such as neural networks, random forest, and reinforcement learning can markedly enhance the accuracy of demand forecasting, route planning, and stock replenishment decisions. Zamini et al. (2022), quoting Georgiev et al. (2024), also highlighted that the ever-increasing amount of real-time data gathered from IoT devices and transaction logistics is making the use of ML not just for forecasting, but also for procurement risk assessment and supplier selection possible. One of the major problems in this area is the lack of interpretability of the ML models, especially in the high-stakes operational use cases, and the availability of large and clean datasets that organizations, especially in developing economies, are not easily able to generate.

3.2 Big Data Analytics and Intelligent Decision-Making

Big data analytics (BDA) has become an integral part of intelligent business analysis and allows companies to derive added value from the various structured and unstructured data they gather along supply chains. Talwar et al. (2021) did a truly important systematic review, which concluded that BDA applications in the operations and supply chain management are broad and cover demand forecasting, supplier risk management, real time visibility, and sustainability. In their model – Dimensions-Avenues-Benefits (DAB) – it is clear that the use of BDA provides competitive intelligence, improves operational efficiency and increases customer responsiveness. Also, Narwane et al. (2021) revealed the contribution of BDA to the implementation of Supply Chain 4.0 in manufacturing organizations of developing economies with highlighting the gaps in terms of data infrastructure. The field has been moving toward distinguishing among different types of analytics as more advanced forms of decision support –

descriptive, predictive and prescriptive – over time (Roy et al., 2022).

3.3 IoT and Real-Time Supply Chain Visibility

The Internet of Things (IoT) has revolutionized supply chain visibility, allowing for the collection of data from physical resources such as vehicles, warehouses and production machinery in a continuous, real-time manner. Ahmed et al. (2021) configured a dyadic review to show how organizations can use IoT connected sensors and RFID technology to track inventory and environmental details, as well as the position of the assets, in a solitary step, which decreases the disparities in data between various tiers along the supply chain. According to Birkel & Hartmann (2020) IoT is the future of risk management in the supply chain, because it allows real-time data streams to provide proactive, not reactive response to disruptions. The difficulties are to deal with cybersecurity issues linked to connected devices and to invest in a big number of capital for putting devices into practice at scale, which are more likely to fall to smaller organizations and providers of lower-income markets.

3.4 Predictive and Prescriptive Analytics in Business Operations

Predictive analytics uses past and current information to make forecasts about the future state of the supply chain and prescriptive analytics extends this by suggesting the best possible action. Seyedan and Mafakheri (2020) analyzed the BDA methods that have been employed for forecasting the demand in the supply chain and found that deep learning architectures and ensemble methods are especially suitable for forecasting in very volatile demand situations. Roy et al. (2022) provided a detailed taxonomy of descriptive, predictive and prescriptive analytics in business decision-making, highlighting that business systems based on causal AI and optimization engines are at the leading edge of intelligent supply chain management. Although there is great potential in prescriptive analytics, organizational readiness for prescriptive analytics – as well as the ability to integrate prescriptive analytics recommendations into enterprise resource planning systems – is still limited.

3.5 Digital Twin and Simulation Technologies

Digital twins, virtual representations of physical supply chain systems, continually updated from real-time data, have proven to be a powerful simulation tool, scenario planning tool and disruption modelling tool. Digital Twins, according to IBM (2022) and operationalized in the literature, are a combination of IoT, ML algorithms and simulation, that help in making dynamic decisions. Van der Valk et al. (2022) conducted a review on digital twin applications in the supply chain and they concluded that digital twins can be used for warehouse optimization, multi-echelon network design, and cold-chain management. Kamble et al. (2022) placed digital twins in the spotlight as important tools in achieving sustainable manufacturing supply chains because of their ability to model sustainability too. There is still a big gap in availability of validated and scalable digital twin platforms for SMEs.

3.6 Resilience, Risk Management, and Disruption Intelligence

The topic of supply chain resilience is once again receiving attention in scholarly circles after the COVID-19 pandemic, and the recent geopolitical disruptions. Katsaliaki et al. (2022) performed a comprehensive review of supply chain disruptions and resilience, outlining readiness, response, recovery and adaptability as key phases of resilience. Chowdhury et al. (2019) created a supply chain resilience scale based on DCT, and they found that resources of connectivity and information-sharing create a visibility capability which further improves the robustness. In recent research, AI and big data analytics are combined with resilience frameworks as intelligent methods for detecting disruptions, such as anomaly detection in IoT data streams or through ML-based risk scoring, which significantly speed up an organisation's response to a disruption in its supply chain (Zamini et al., 2022).

IV. CONCEPTUAL FRAMEWORK: THE INTELLIGENT SUPPLY CHAIN OPTIMIZATION FRAMEWORK (ISCOF)

Based on this, the Intelligent Supply Chain Optimization Framework (ISCOF), which conceptualizes the optimization of supply chains and

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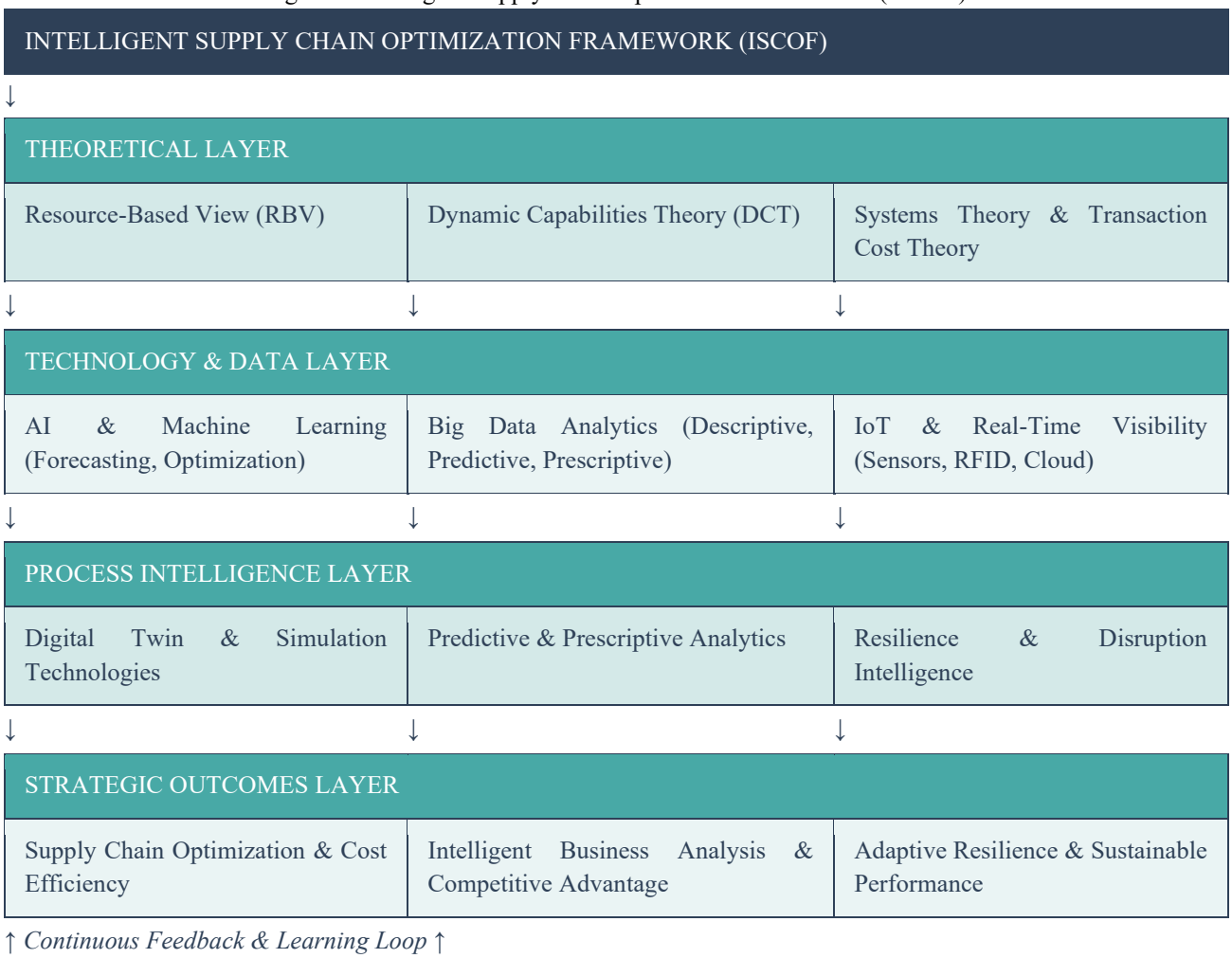
the intelligent business analysis as the result of the layered interaction of the theoretical background, technological enablers and strategic outcomes, is proposed in this review. The ISCOF consists of four layers: (1) Theoretical Layer, which is based on RBV, DCT, Systems Theory, and Transaction Cost Theory; (2) Technology and Data Layer, which includes AI/ML, big data analytics and the Internet of Things; (3) Process Intelligence Layer, which incorporates digital twins, predictive/prescriptive analytics, and resilience intelligence; and (4) Strategic Outcomes Layer, which delivers supply chain optimization, competitive advantage, and adaptive resilience. The outcomes are directly tied to the theoretical development and technological investments through a continuous feedback and learning cycle, which is characteristic of an intelligent supply chain system. This multi-layered structure extends the knowledge of previous models, specifically connecting theory, technology and technology decisions, and showing the mapping of process level intelligence to strategic level performance.

Figure 1: Intelligent Supply Chain Optimization Framework (ISCOF)



V. DISCUSSION

Looking at the six thematic areas in which the technologies have been examined, there are clear indications of the potential of intelligent technologies to transform supply chain performance. AI, big data, IoT and digital twin technologies can produce a data-rich supply chain operating environment that facilitates real-time visibility, predictive foresight, and adaptive reconfiguration – something that was

not possible in traditional supply chain architectures (Toorajipour et al., 2021; Talwar et al., 2021). Organizations that are successful in using these technologies generally attain a higher level of demand forecasting accuracy, reduced inventory carrying cost, improved response to disruptions and better supplier risk assessment results. Theoretically, literature has always supported RBV and DCT as explanatory frameworks, validating the use of data and analytics as strategic assets that can create a competitive advantage in the business world for a longer time.

But there are still some differences. First, the pros and cons of predictive versus prescriptive analytics have been discussed: some researchers believe that prescriptive analytics are the ultimate form of decision support, whereas others contend that the challenges to organizational readiness for prescriptive analytics (data quality, lack of human resources, and issues with algorithmic decision-making) make it premature for most organizations to use them (Roy et al., 2022). Second, there are conflicting views regarding the pace and viability of digital twin adoption: data from large resource companies in developed countries shows measurable benefits, but the empirical data in SMEs and emerging economy contexts is limited (Kamble et al., 2022). Third, the optimization literature tends to have an efficiency focus, while the resilience literature has an orientation toward adaptation – and the combination of the two, such as in the ISCOF, remains under-developed.

The results of this research underscore the critical importance of making a smart investment in data infrastructure, cross-functional data analytical skills, and change management skills before implementing AI or digital twin tools. The challenge for researchers is to develop medium-range models that connect specific technological configurations to performance in a variety of organizational and institutional settings -- including, crucially, the Global South -- which are so far poorly represented in the literature.

VI. RESEARCH GAPS AND FUTURE DIRECTIONS

There is a need for investigations in certain areas which don't have much study done. First, the integration of the three technologies, namely AI, IoT and digital twin, is not well theorized, as most studies focus on only one of the three technologies at a time. Second, there is a scarcity of empirical studies from emerging economy supply chains, where institutional barriers, lack of digital infrastructure, and regulation play an important role in shaping technology adoption trajectories. Third, human-machine collaboration in intelligent supply chain decision-making has not been deepened: how managers react to the algorithmic recommendations, on which conditions they reject them, and what they gain and lose in terms of performance. Third, there is still a lack of deepening of human-machine collaboration for intelligent supply chain decision making: under what conditions is the algorithmic recommendation accepted, what conditions are ignored, and what performance gains and losses occur. Longitudinal multi-case studies in different geographical settings, experimental designs to test performance implications of integrated technology stacks, and theory development in human-AI teaming in SCM are suggested for future research plans.

VII. RECOMMENDATIONS

Data governance frameworks that provide the necessary data quality, interoperability and security throughout the supply network partners should be a top priority for organizations aiming to accelerate the supply chain optimization and intelligent business analysis. To enable intelligent systems, scalable cloud-based analytics platforms should be installed first, with advanced AI or digital twin tools coming next: Data infrastructure maturity is the key enabler of intelligent systems. Cross-functional analytics skills are essential for supply chain managers to understand and put into action the insights and recommendations from AI. Policymakers around the world should develop enabling environments to help intelligent supply chain technologies spread quickly among SMEs, especially in developing economies, by investing in digital infrastructure, ensuring

regulatory clarity, and facilitating public-private partnerships. It is crucial to jointly design models for responsible AI in supply chains, with an emphasis on algorithmic bias, transparency, and accountability as AI-driven systems are gaining decision-making power. Academicians and practitioners need to work together to co-design models for responsible AI in supply chains, focusing on issues such as algorithmic bias, transparency, and accountability as AI-driven systems become more influential in decision-making processes.

VIII. CONCLUSION

This conceptual review has identified key developments in supply chain optimization and intelligent business analysis that have occurred over the past year from the perspective of six thematic areas: AI and ML, big data analytics, IoT, predictive and prescriptive analytics, digital twin technologies and resilience intelligence. The literature demonstrates the transformative capability of these developments, and also identifies certain integration gaps, the use in emerging economies, and collaboration between humans and algorithms. The idea of ISCOF provides a framework with a solid theoretical base to support the conceptualization of the relationship between the intelligent technologies and the results of the supply chain and business performance. This review is of wider interest because it is part of an emerging but fast-growing field at the nexus of operations management, data science and strategic management which will come to play an increasing role in the competitiveness of organisations and the reliability of global trading in times of increasing uncertainty.

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