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Exploring the performance of digitalized supply chains

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Abstract

This study explores the concept of digitalized supply chains through a conclusive literature review, establishing a background and defining key terminologies. The advantages and disadvantages associated with digitalized supply chains are identified with the help of existing research and analyzing relevant case studies. Furthermore, the study examines emerging trends and their key performance indicators (KPIs) that measure improvements in inventory management, order fulfillment, and customer satisfaction to gain deeper insights into the digital market dynamics. The analysis concludes with an initial conceptual model for the digital supply chain. The possible future scope of this work can include the development of a framework, simulations, and physical implementation. The study's future work could be recommendations for organizations aiming to enhance their supply chain performance through digitalization, equipping them with the tools necessary to navigate future challenges in a rapidly evolving market.

Keywords
Digitalized Supply Chain, Key Performance Indicators, Digital Transformation, Operational Excellence, Digital Extended Value Stream Map (DEVSM)

1. Introduction
Supply chain refers to the network of organizations, activities, resources, and technologies involved in producing and distributing goods and services from raw materials to end consumers. The supply chain covers all the processes required to design, source, manufacture, and deliver products or services. The key components of a supply chain start with the suppliers who provide the raw materials needed for production next comes the manufacturers who convert the raw materials into the finished products, and then going to the distributors who handle all the logistics of

transporting the products, after that comes the retailers the ones who sell the products to the customers the ones at the end of the supply chain and the end users of the product or service. The supply chain performance can be measured through several key metrics one of them is efficiency, responsiveness that includes lead time and flexibility, quality, cost, and sustainability. Supply chain performance could still improve in different ways one of them is using the collaboration between all parties in the supply chain, also following lean principles to reduce waste and improve efficiency, risk management could be another way of improvement since it identifies and removes risks that could disrupt the supply chain, and the last tool to improve the supply chain performance is technology integration of the use of software and data analytics for better forecasting and inventory management.

The supply chain can be approached from two perspectives: business administration and engineering. The business administration view focuses on strategic and operational management, aiming to optimize efficiency, reduce costs, and align supply chain activities with business goals through tools like ERP systems and analytics. In contrast, the engineering perspective emphasizes technical and production aspects, applying methodologies like Lean Manufacturing and Six Sigma to improve processes, automation, and product quality. A digitalized supply chain uses advanced technologies such as IoT, AI, cloud computing, and blockchain to improve visibility, efficiency, and responsiveness. Real-time data monitoring, predictive analytics, automation, and enhanced collaboration enable companies to optimize operations, reduce costs, and adapt to market changes. This transformation fosters innovation, streamlines processes, and creates a more agile, customer-centric approach to supply chain management, helping organizations stay competitive in a fast-evolving market.

1.1 Objectives
This study explores the supply chain by defining its structure, identifying problems like visibility, and speed, and examining key performance indicators (KPIs). It investigates solutions to improve performance, focusing on the concept of the digitalized supply chain as a transformative approach. The study delves into trends, structure, KPIs, challenges, and opportunities in digitalized supply chains, highlighting gaps and limitations companies face in adopting them. By understanding traditional and digitalized supply chains, the research aims to identify challenges and provide insights to bridge the gap in implementing digitalized supply chains effectively.

2. Methodology
The project focuses on a literature review to provide a background and define the concept of a digitalized supply chain. With the help of other research and case studies, the advantages and disadvantages of a digitalized supply chain can be listed. In addition, the new trends and their KPIs in the digitalized market are highlighted to understand their dynamics in depth. Finally, after analyzing the trends and their performance, and figuring out the limitations and challenges, the project provides an appropriate model to represent the Digital supply chain.

3. Literature Review
This literature review begins by examining traditional supply chains, their models, key performance indicators (KPIs), and challenges. It then transitions to digitalized supply chains, exploring their features, trends, and KPIs. The review highlights challenges in transitioning to digitalized supply chains, such as high implementation costs, cybersecurity risks, and resistance to change, while discussing innovations like IoT, Industry 4.0, and cloud manufacturing that drive modernization.

3.1 Traditional Supply Chain
A supply chain is a network involving individuals and companies collaborating to create and deliver products to consumers, encompassing raw material suppliers to the transportation of finished goods. There are three primary supply chain models: the continuous flow model, suited for high-demand products requiring minimal redesign; the fast chain model, ideal for trend-driven industries like fast fashion; and the flexible model, designed for managing seasonal or holiday goods with fluctuating demand. (Hayes, 2024)

Additionally, supply chain management encompasses five critical flows: product, financial, information, value, and risk flows. Product flow ensures efficient movement of goods between suppliers and customers, financial flow manages payments and credits, and information flow simplifies the sharing of essential data such as orders and inventory. Value flow focuses on enhancing worth at each stage, while risk flow addresses potential disruptions. Effective coordination of these flows is essential for optimizing efficiency and ensuring seamless supply chain operations. (Bsaikrishna, 2018)

3.1.1 Models

The study by Gupta et al. (2020) examines the advancements in Additive Manufacturing (AM) and their implications for supply chain management, emphasizing AM's flexibility and customization capabilities. It identifies three AM supply chain models tailored to different industry needs. The first model involves large-scale production, where manufacturers own 3D printers and adhere to strict design specifications, as seen in the automotive sector. The second model treats design files as the product, enabling customers to print parts themselves or through job shops, exemplified by NASA's use of 3D printing on the ISS. The third model separates physical supply chain management from design file control, often used in markets like classic car parts, allowing customers to source designs and print parts as needed. The study highlights AM's integration of virtual and physical supply chains, forming cyber-physical systems with unique cybersecurity risks and operational challenges. Unlike traditional linear supply chains, which rely on processes like casting and machining, AM supply chains are adaptable, supporting localized production alongside traditional distribution methods. With the help of the studies (Hayes, 2024), (Bsaikrishna, 2018), and (GUPTA et al. 2020), a model of a traditional manufacturing supply chain was constructed to illustrate its features, including the five critical flows; product, financial, information, value, and risk, that ensure seamless operation. Figure 1 shows that customers can either place orders directly with suppliers or communicate with manufacturers, depending on company policies. Once manufacturing is complete, the product moves to distributors, retailers, and finally to the customer. The model highlights a flexible structure adaptable to various organizations, and how traditional supply chains manage interactions and flows efficiently.

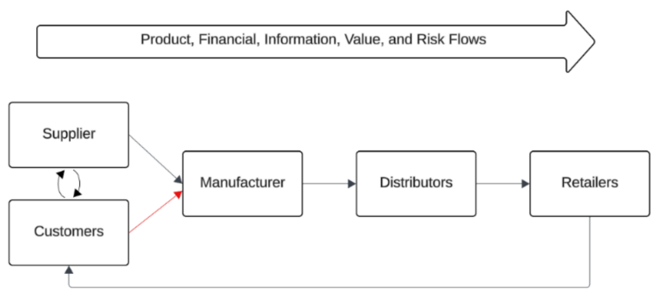

Figure 1. Traditional Supply Chain Model

Based on the discussions in Hayes (2024), Bsaikrishna (2018), and Gupta et al. (2020)

The case study in (Jones, 2022) highlights a manufacturer transitioning from optimizing internal processes with a Value Stream Map (VSM) to adopting an Extended Value Stream Map (EVSM) to address inefficiencies across the entire supply chain. While VSM focuses on improving workflows within a single organization, EVSM expands to include suppliers and customers, fostering collaboration and system-wide optimization. This shift enabled better performance, cost efficiency, and waste reduction by analyzing delays, inventories, and variations across the supply chain. EVSM provides a detailed, comprehensive reference for data and analysis, emphasizing broader goals over isolated improvements. The book “Seeing the Whole Value Stream” (Jones et al., 2011) emphasizes the importance of mapping the value stream to identify inefficiencies, bottlenecks, and waste, enabling organizations to optimize processes for greater efficiency and customer satisfaction. It introduces the Extended Value Stream Map (EVSM), which visualizes the entire supply chain—from suppliers to customers—focusing on eliminating waste, improving flow, and enhancing collaboration for system-wide optimization. A lean EVSM aligns processes to customer value, reduces delays, simplifies operations, and fosters seamless material and information flow. Key features include awareness of takt time, minimal inventory levels, responsive transportation, streamlined information processing, short lead times, and cost-effective changes to improve flow. These principles ensure the value stream operates harmoniously, delivering maximum value with minimal waste.

After understanding what is a Value stream map and an Extended value stream map, it is now clear how a value stream map can represent a facility's supply chain. First, the customer sends an order to the supplier and the supplier then sends the details to the manufacturers. Next, the manufacturer lets the facility know how much raw materials and supplies are needed to begin manufacturing. After the product is done it goes to the distributor, the retailer, and finally reaches the customer as shown in Figure 2 below. This model's focus was on presenting the traditional supply chain through an extended value stream map.

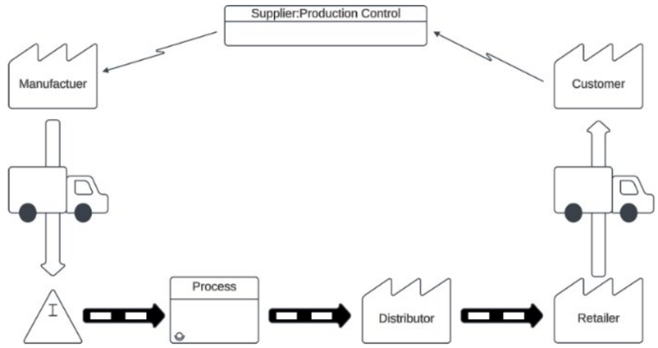

Figure 2. Traditional Supply Chain Model

3.1.2 KPIs

The study (Deif & Nounou, 2023) highlights three key supply chain KPIs; Responsiveness, Uniformity, and Steadiness, designed to align with a lean framework and assess delivery performance. Responsiveness measures the ratio of actual delivery flow to demand rate, reflecting agility. Uniformity evaluates the consistency of flow rates over time, while Steadiness tracks flow stability within specific intervals to identify variations. These KPIs form the foundation of the Supply Chain Flow Dashboard (SCFD), enabling performance improvement and better alignment with customer demand.

Key Performance Indicators (KPIs) are essential for effective supply chain management, with studies highlighting various metrics to optimize performance. FourKites (2022) identifies eight critical KPIs, including On-Time Delivery and Estimated Time of Arrival (ETA), which measure delivery reliability. Inventory to Sales Ratio (ISR) evaluates inventory management efficiency while the carrying cost of Inventory and tracks expenses like insurance and obsolescence. Purchase Order Tracking monitors real-time procurement status, and Days Sales of Inventory (DSI) assesses inventory turnover, impacting cash flow. Freight Cost per Tonne Shipped analyzes transportation cost efficiency, and Perfect Order Delivery Rate measures the accuracy and timeliness of deliveries. Supplier On-Time Delivery evaluates suppliers' punctuality, ensuring smooth operations. These KPIs help align processes with customer needs and enhance supply chain efficiency.

Additional studies expand on these metrics, emphasizing broader aspects of supply chain performance. Mueller (2024) and insightsoftware (2024) highlight the Perfect Order Rate, Cash-to-Cash Cycle Time, Fill Rate, and Inventory Turnover as key metrics for tracking efficiency and responsiveness. Unique KPIs such as Reasons for Return provide insights into quality or fulfillment issues, while Supply Chain Cycle Time measures responsiveness in fulfilling orders without inventory on hand. Freight Bill Accuracy ensures precise billing and metrics like Warehouse Capacity Utilization and Customer Order Cycle Time assess operational precision and delivery speed. Keeports (2024) and Dilmegani (2024) also emphasize common KPIs like On-Time Delivery, Order Accuracy Rate, and Freight Cost per Unit, which aid in cost management and optimization. Together, these KPIs provide a comprehensive framework for monitoring and improving supply chain performance.

3.1.3 Challenges

The studies by Seyedkolaei and Nasseri (2023) and Mustapha et al. (2022) address critical aspects of supply chain design and resilience. Seyedkolaei and Nasseri focus on optimizing supply chain network design through a mathematical model utilizing integer linear programming to strategically locate distribution centers. The model aims to minimize transportation and facility setup costs while improving efficiency and reducing operational expenses. Using an iterated local search algorithm, the study achieved faster, optimal solutions and positively impacted KPIs such as responsiveness, inventory carrying costs, and perfect order delivery rates. The research suggests future work should incorporate supplier and warehouse dynamics for a more holistic network design. Mustapha et al. examine the impact of the COVID-19 crisis on supply chain disruptions, emphasizing Collaborative Resource Sharing (CRS) as a recovery strategy. CRS optimizes labor, material, and information resource allocation, enhancing resilience, reducing costs, and improving service quality. By systematically reviewing literature from 2000 to 2022 and employing text mining and clustering techniques, the study highlights the importance of collaboration and resource prioritization during disruptions. Key KPIs, including responsiveness, uniformity, steadiness, and supplier on-time delivery, are identified as essential for improving communication and performance in disrupted supply chains.

Traditional supply chains face numerous challenges, including a lack of visibility, reliance on manual processes, and poor synchronization among participants, leading to inefficiencies, delays, and high costs. Unpredictable demand patterns, long lead times, and rigid structures further hinder adaptability to market changes. Additionally, the complexity and cost of integrating new technologies, insufficient collaboration across functions and with external partners, poor data management, and labor shortages exacerbate operational inefficiencies. Studies (Smartmakers, 2024), (Hawkins, 2024), and (Jenkins, 2024) highlight these issues, emphasizing common challenges like inventory inaccuracies, demand forecasting difficulties, and limited flexibility. To address these challenges, solutions include adopting IoT-based technologies for real-time data, improving collaboration, and enhancing data management practices. Advanced technologies and better synchronization across supply chain participants are particularly critical for enhancing responsiveness, adaptability, and overall efficiency.

3.2 Digitalized Supply Chain
Traditional supply chains are often linear and rely on separate systems and historical data, limiting real-time visibility and making predicting and adapting to disruptions difficult (Jenkins, 2022). In contrast, digital supply chains function as dynamic networks integrating IT and operational technology systems, providing real-time data access and proactive problem-solving to enhance efficiency and responsiveness. Key features of the digital supply chain include end-to-end visibility, real-time data, advanced analytics, automation, and improved collaboration, all of which optimize decision-making, reduce errors, and increase agility in response to market changes (Sturim, 2024). This transformation, or Supply Chain 4.0, replaces manual processes with digital solutions, focusing on digitized data management, seamless process integration, and digital tools to enhance physical operations, ultimately creating a more agile and effective supply chain (Flora, 2024).

3.2.1 Trends
The study (Flora, 2024) identifies key trends in digitalized supply chains, including increased reliance on real-time data and analytics for better inventory management and demand forecasting. Enhanced integration improves connectivity and transparency across systems. Automation and robotics, such as warehouse robots, streamline physical operations, while AI and machine learning enable predictive analytics and smarter decision-making. The Internet of Things (IoT) facilitates real-time tracking and monitoring of goods. Additionally, sustainability efforts are driving eco-friendly strategies to reduce waste. Together, these trends contribute to more efficient, transparent, and sustainable supply chains.

Similarly, the study (Jenkins, 2022) highlights the growing role of AI, automation, and IoT in addressing traditional supply chain challenges. AI and automation improve predictive analytics and demand forecasting, while IoT offers real-time data for better inventory and shipment management. Cloud computing enhances collaboration, and many companies are adopting generative AI to improve supply chain operations. Integrated supply chain management platforms are also simplifying operations, making it easier to manage disruptions, and marking a shift toward more intelligent and adaptable supply chain systems.

3.2.2 Models
The study by Dallasega (2018) explores the challenges of transitioning traditional supply chains to digitalized systems within the engineer-to-order (ETO) manufacturing industry. ETO supply chains face variability and unpredictability in on-site processes, leading to inefficiencies, extended lead times, and errors. To address these issues, the study applies Industry 4.0 principles and proposes a supply chain framework integrating Just-In-Time (JIT) and self-regulation strategies. This pull-based system is triggered by downstream demand, ensuring timely material delivery and dynamic adaptation to fluctuations. Self-regulation mechanisms optimize resource use, reduce waste, and enhance efficiency across upstream suppliers, manufacturers, and downstream construction sites. Key features include centralized coordination, direct supply routes for critical components, and strategic placement of the Order Penetration Point (OPP) for customization. The framework aligns with lean and Industry 4.0 principles, enhancing material and information flow while minimizing lead times. The study illustrates the integration of self-regulation, pull mechanisms, and direct supply routes in optimizing ETO digitalized supply chains.

The study by Garay-Rondero et al. (2019) presents a Digital Supply Chain (DSC) model tailored for the Industry 4.0 landscape, offering a multi-dimensional framework for modern supply chain management. The model integrates six core dimensions: digital and physical components, interconnected network structures, Industry 4.0 technologies, supply chain flows, the virtual value chain, and the convergence of digital and physical worlds. Leveraging technologies like AI, IoT, blockchain, and cyber-physical systems (CPS), the DSC enables real-time data integration, transparency, traceability, and automation. This shifts traditional linear supply chains into dynamic, collaborative ecosystems, improving response times, operational efficiency, and value creation while addressing customer demands and sustainability. The model by Garay-Rondero et al. (2019) illustrated as a multi-layered network, includes a central DSC core supported by cloud computing and robotics for real-time processing, automation, and decision-making. Surrounding this are CPS to bridge digital and physical activities, and an outer Virtual Value Creation layer that emphasizes digital benefits like real-time access, digital service, and seamless integration. The model also underscores the coordination of supply chain flows; products, materials, services, and information, to enhance agility, resilience, and resource efficiency.

The studies by PricewaterhouseCoopers (2024) and OpenText (2024) explore the transformative impact of Industry 4.0 on supply chain management, emphasizing the shift from traditional supply chains to interconnected, intelligent, and customer-focused digital networks. The Digital Supply Chain (DSC) model integrates advanced technologies like IoT, AI, blockchain, and cloud computing to enable real-time data sharing, seamless collaboration, and predictive analytics. Key elements include automated warehousing, real-time logistics tracking, optimized sourcing, and risk prevention through analytics, enhancing scalability, transparency, and agility. The DSC connects four main stakeholders; Customer, Supplier, Production, and Distributor, by managing information flows such as planning, orders, and updates, alongside real-time product tracking. According to the studies, this integration reduces waste, shortens lead times, and supports sustainability while enabling businesses to adapt quickly to market changes, improve service delivery, and enhance customer satisfaction.

Figure 3 based on the understanding from the studies (Dallasega, 2018), (Garay-Rondero et al., 2019), (PricewaterhouseCoopers, 2024), and (OpenText, 2024) explains a Digital Supply Chain (DSC) as the central hub, seamlessly connected to key stakeholders: Supplier or Partners, Facility, Distributor, Retailer, and Customer. Each connection represents essential interactions such as planning, ordering, confirming, quality assurance, and status updates, while additional flow lines between stakeholders enable tracing and tracking for real-time visibility of product status. The system operates on self-regulation, Just-In-Time (JIT), and pull methods, ensuring that materials and products flow based on actual demand, reducing waste, and optimizing resources. Surrounding the DSC and its stakeholder connections is a layer of Cyber-Physical Systems (CPS), powered by technologies like sensors and IoT devices, enabling real-time data collection and automation. Covering the CPS layer is the Industry 4.0 layer, incorporating advanced technologies such as AI, blockchain, and robotics to drive the digitization and optimization of supply chain processes. The outermost layer represents important flows, including products, services, materials, returns, real-time information, knowledge, risks, and finances, highlighting the interconnected and dynamic nature of the DSC, designed to enhance efficiency, transparency, and resilience.

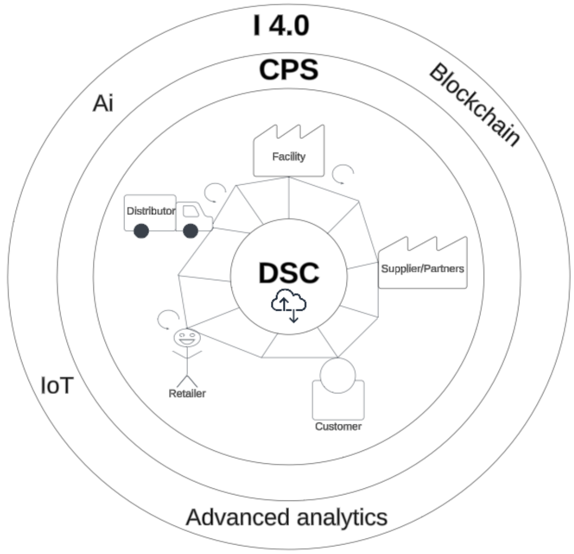

Figure 3. Digital Supply Chain Model

Based on the discussions in Dallasega (2018), Garay-Rondero et al. (2019), PricewaterhouseCoopers (2024), and OpenText (2024)

3.2.3 KPIs

The studies by Bridges (2024) and Tang (2024) identify several key performance indicators (KPIs) to assess the effectiveness of a digital supply chain. These include the Supply Chain Digital Maturity Level, which measures the integration of digital technologies, and Cloud-Based Supply Chain Solutions Utilization, which tracks the adoption of scalable cloud technologies. The AI Adoption for Demand Planning KPI evaluates the use of AI in improving demand forecasting accuracy. Other KPIs such as Real-Time Inventory Tracking and the Supply Chain Visibility Index focus on inventory management and transparency. Blockchain Adoption assesses the implementation of blockchain for securing supply chain transactions, while IoT device deployment density measures the use of IoT devices for data collection and monitoring. The Digital Twin Accuracy KPI evaluates how well digital twins replicate physical assets for simulation. Automated Inventory Reorders track the system's ability to reorder stock based on demand forecasts, and the Supply Chain Agility Index measures the supply chain’s responsiveness to market changes and disruptions. These KPIs can help organizations improve operational efficiency, enhance responsiveness, and optimize supply chain strategies for better collaboration and customer satisfaction.

3.2.4 Challenges

The studies by Reynolds (2024), Digital Supply Chain Management (2024), and Amos (2024) highlight significant challenges in transitioning to digital supply chains. Key obstacles include data integration difficulties in unifying legacy and modern systems, cybersecurity vulnerabilities that demand robust protective measures, and organizational resistance driven by employee concerns and reluctance to adopt new technologies. Effective change management and training are essential to address these issues. Financial constraints, particularly for SMEs, further complicate the transition due to high initial investment costs for technologies like cloud computing, IoT, and machine learning. Integration with legacy systems often creates inefficiencies, which can be mitigated with scalable, flexible solutions. Maintaining continuous visibility across vast data volumes is another challenge, but real-time tracking and analytics offer potential solutions. Overall, strategic planning and investment are critical to overcoming these barriers and enabling successful digital supply chain transformations that enhance efficiency, visibility, and competitiveness.

3.3 Transformation from Traditional to Digitalized Supply Chain

The study by Domingos et al. (2024) explores how enabling technologies (ET) can enhance supply chain resilience. Traditional information systems are criticized for their inability to support effective resilience strategies, but advancements in Industry 4.0 technologies may address this gap. The research combines a systematic literature review with case studies from three sectors in Brazil, Canada, and Italy: an agri-food company, a food manufacturing firm, and a logistics provider. The study develops a framework for using ET to strengthen resilience, offering practical insights and recommendations for future research.

The study by Yue & Chen (2018) examines how economic globalization and increasing market competition have shifted rivalry from businesses to entire supply chains. The Internet of Things (IoT) significantly impacts the spatial structure and economic relationships within supply chains, affecting resource allocation and operations. This introduces new management challenges and opportunities for innovation. Using fuzzy theory and possibility theory, the study develops a model to optimize manufacturing resource allocation strategies within the IoT framework, aiming to meet product order fulfillment while minimizing inventory costs. Simulation results confirm the model's effectiveness. Additionally, IoT-generated data can be transformed into valuable resources, forming new data-driven services that alter the traditional supply chain structure and power dynamics between upstream and downstream enterprises.

The study by Lu et al. (2020) explores cooperative decision-making in a cloud service supply chain involving a cloud application developer (CAD) and two cloud service providers (CSPs). The study frames the problem as a "patent labeling" game to analyze the CAD's labeling and supply strategies under varying confidence levels. Since confidence levels are hard to measure, the Shapley value contract is used to divide profits, and a cooperative subsidy mechanism is proposed to achieve better outcomes than a simple wholesale pricing contract. The analysis shows that when the CAD is highly optimistic or pessimistic, it prefers to collaborate with the more established CSP, and labeling is considered only when the CAD is pessimistic and labeling costs are low. For intermediate confidence levels, a hybrid contract combining the Shapley value and cooperative subsidy mechanism is recommended.

The studies by Horsthofer-Rauch et al. (2022) and Bega et al. (2023) examine the evolution of Value Stream Mapping (VSM) with digital technologies, transitioning from traditional methods to digital tools that enhance efficiency and accuracy. By integrating real-time data collection and analysis, digital VSM improves process visualization and decision-making, though challenges such as technological infrastructure requirements and system integration complexity remain. Future research should focus on developing standardized frameworks to facilitate the widespread adoption of digitalized VSM across industries. The Digital Value Stream Map (DVSM) builds upon traditional VSM by incorporating IoT and real-time analytics, optimizing workflows, reducing waste, and improving efficiency, while also laying the groundwork for extending value stream improvements beyond internal operations. Additionally, Bega et al. (2023) introduce VSM 4.0 plus, an enhanced methodology that refines VSM 4.0 by adding data point specifications, technical details, and data processing insights, ultimately improving communication between production and software engineers and enhancing the management of data flows in manufacturing processes.

3.4 Digitalized Extended Value Stream Map (DEVSM) – A new model

The Digital Extended Value Stream Map (Digital EVSM) is a development that expands the scope of traditional VSM beyond the organization's internal operations to encompass the entire supply chain. It includes suppliers, customers, and logistics partners, emphasizing end-to-end visibility, collaboration, and optimization. Digital EVSM maps data flows, communication protocols, and information-sharing mechanisms across multiple entities to create a comprehensive view of the value chain. This broader perspective enables cross-organizational improvements, fostering greater efficiency, transparency, and cooperation throughout the supply chain. The DEVSM provides a detailed, visual analysis of specific processes, identifying inefficiencies, and guiding improvements.

3.4.1 Model Requirements

A Digital Extended Value Stream Map (DEVSM) requires several critical requirements to function effectively. These include a robust technological infrastructure including IoT devices, cloud platforms, and advanced software for data processing and analytics. Seamless integration with existing systems is ensured through standardized protocols for data sharing and compatibility. Stakeholder collaboration is essential, requiring training and active participation from all supply chain participants. The system must also be scalable and flexible to adapt to growing or evolving supply chains. The main requirements for a DEVSM are Supply chain end-to-end visibility which is the ability to track and monitor goods, data, and financial flows across the entire supply chain in real time, ensuring transparency and improved decision-making. Operational excellence is another requirement that focuses on optimizing processes, reducing waste, and enhancing efficiency to achieve superior performance and customer satisfaction. Finally, Digitalization involves leveraging advanced technologies like IoT, AI, and cloud computing to transform traditional supply chains into interconnected, data-driven ecosystems that enhance agility and responsiveness.

The DEVSM includes features designed to meet these requirements like End-to-end visibility enabling real-time monitoring of material, information, and financial flows, and using IoT devices and cloud platforms for comprehensive oversight. Data integration ensures seamless communication across diverse systems, aligning with compatibility needs. Real-time analytics and visualization tools provide actionable insights into key metrics, while scenario modeling supports decision-making and adaptability. Smart automation, powered by AI, machine learning, and smart contracts, enhances forecasting and process efficiency, addressing the need for operational optimization. Finally, collaboration tools and secure data-sharing mechanisms foster stakeholder alignment, ensuring compliance, security, and effective communication. Together, these features and requirements work to streamline and enhance the efficiency, visibility, and collaboration of supply chains.

3.4.2 Initial conceptual model

The Digital Extended Value Stream Map (DEVSM) is an advanced, interactive tool designed to visualize and optimize the entire supply chain by integrating real-time data and analytics. It connects entities such as suppliers, manufacturers, and distributors through seamless flows of materials, information, and finances. Equipped with IoT connectivity, the Digital EVSM provides real-time updates, while dashboards display key performance metrics like lead times and inventory levels. Smart contracts automate critical processes such as payments and approvals, and collaboration portals facilitate real-time data sharing and issue resolution among stakeholders. Adaptable to complex supply chain scenarios, the Digital EVSM enhances visibility, fosters collaboration, and drives continuous optimization. Figure 4 is an initial conceptual model that positions the supply chain as the central hub, linking other stakeholders like manufacturers, process operations, distributors, retailers, and customers. This model features electronic message arrows to represent seamless information, material, and financial flows, ensuring end-to-end visibility and efficient collaboration. Key elements include data integration, collaborative tools, real-time analytics, and visualization, which support improved decision-making and operational efficiency. The supplier-manufacturer connection is highlighted as crucial for ensuring visibility and coordination across production and supply activities. The Digital EVSM relies on advanced technological infrastructure, active stakeholder participation, and consistent operations to transform traditional supply chains into transparent, efficient, and collaborative systems. Figure 5 is the key to help understand the DEVSM more clearly.

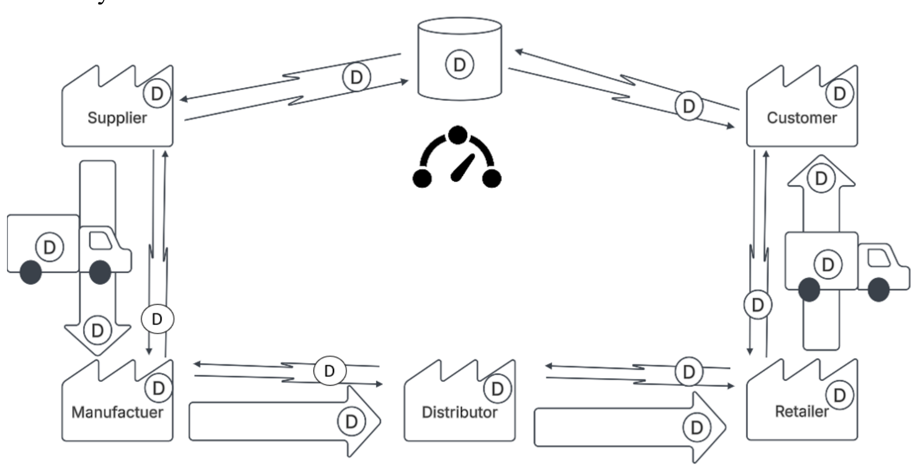

Figure 4. DEVSM conceptual Model

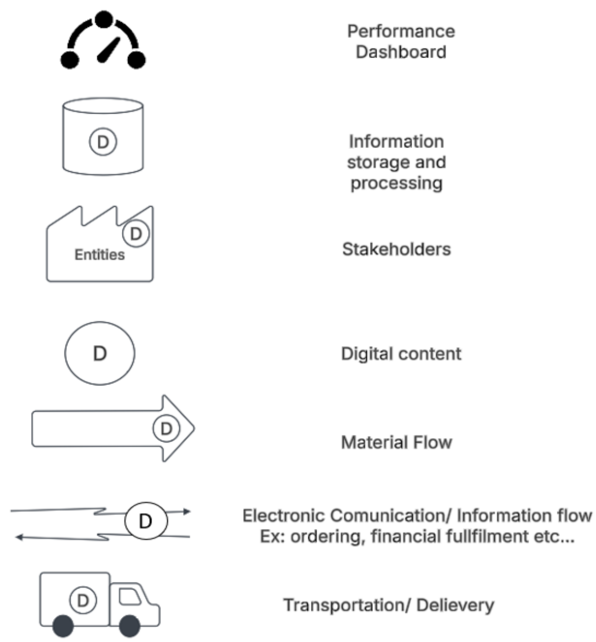

Figure 5. DEVSM conceptualization of the components

3.4.3 Conceptual DEVSM KPIs

The specific Key Performance Indicators (KPIs) for the Digital Extended Value Stream Map (DEVSM) are to be determined with the future detailed construction of the model. However, some conceptual ideas can be proposed based on the core requirements of DEVSM. For end-to-end visibility, a potential KPI is data sharing effectiveness, which measures the seamless exchange of information across stakeholders to enhance transparency and coordination. About operational excellence, the order fulfillment rate serves as a key metric, reflecting the ability of the supply chain to meet customer demands efficiently while minimizing delays and disruptions. Lastly, for digitalization, the extent of implementation of digital tools can be a crucial KPI, assessing the degree to which advanced technologies, such as IoT, AI, and real-time analytics, are integrated into the DEVSM framework. These conceptual KPIs will serve as a foundation for further modification and validation as the DEVSM model is developed in greater detail.

5. Results and discussion

The Digital Extended Value Stream Map (DEVSM) provides a comprehensive view of the entire supply chain, enabling stakeholders to identify inefficiencies and optimize processes across the value network. By integrating real-time data and shared systems, DEVSM enhances collaboration among suppliers, manufacturers, and customers, facilitating better communication and coordination. Mapping interdependencies strengthens supply chain resilience, allowing organizations to streamline data flows through standardized protocols. Additionally, DEVSM aligns production with customer demands, driving customer-centric improvements and overall supply chain performance.

This outcome addresses a critical research gap in the representation of digital supply chains through DEVSM, expanding beyond traditional Digital Value Stream Mapping (DVSM), which primarily optimizes internal processes within individual facilities. Unlike DVSM, DEVSM incorporates external stakeholders such as suppliers, partners, and customers, offering a holistic perspective on the value stream. This highlights the potential of DEVSM as a tool to bridge internal operations with the extended supply network. Leveraging real-time data, advanced analytics, and digital platforms, DEVSM enables organizations to identify inefficiencies, reduce lead times, and enhance collaboration at every stage of the supply chain. The integration of DEVSM into supply chain operations not only drives digital transformation but also significantly improves responsiveness, adaptability, and overall performance.

A comparative analysis of different supply chain models; Value Stream Mapping (VSM), Extended Value Stream Mapping (EVSM), Digital Supply Chain (DSC), Digital Value Stream Mapping (DVSM), and Digital Extended Value Stream Mapping (DEVSM) is presented in a table highlighting their alignment with key requirements: end-to-end visibility, operational excellence, and digitalization. The table reveals that VSM focuses solely on operational excellence, lacking visibility and digital capabilities. EVSM extends the scope to include both operational excellence and end-to-end visibility, enabling a more comprehensive analysis of supply chain processes. The Digital Supply Chain (DSC) aligns with end-to-end visibility and digitalization; however, its contribution to operational excellence is debatable, since its focus on connectivity and automation may improve efficiency but does not directly address all process optimization aspects. DVSM addresses operational excellence and digitalization but does not account for the extended visibility across external stakeholders. Finally, the DEVSM covers all three requirements end-to-end visibility, operational excellence, and digitalization making it the most comprehensive model for modern supply chain optimization. This comparison underscores the value of DEVSM in bridging the gaps of previous models and advancing supply chain performance through integrated digital tools and real-time data as shown in Table 1.

Table 1. Models comparison results

Models	Model requirements		
	End-to-end visibility	Operational Excellence	Digitalization
VSM		√	
EVSM	√	√	
DSC	√	(√)	√
DVSM		√	√
DEVSM	√	√	√

6. Conclusion

This literature review examined the evolution of supply chains from traditional to digitalized systems, focusing on models, KPIs, challenges, and transformative technologies. Traditional supply chains revealed inefficiencies and limited visibility, while digitalized systems addressed these issues through advancements like Industry 4.0, IoT, cloud manufacturing, and Engineer-to-Order (ETO) systems, overcoming challenges such as high costs, cybersecurity risks, and organizational resistance. The Extended Value Stream Map (EVSM) was identified as a critical tool for enhancing value delivery by optimizing inefficiencies. Building on this, the study proposed a Digital Extended Value Stream Map model that incorporates advanced digitalization elements such as real-time data integration, end-to-end visibility, and cross-functional collaboration to address the complexities of modern supply chains. The study also introduces conceptual KPIs that could be updated in the future and measured through the DEVSM model and explains why the DEVSM is a useful tool to present a supply chain with end-to-end visibility, operational excellence, and digitalization.

7. Future work

This study introduces a novel conceptual model for a digitalized supply chain based on Extended Value Stream Mapping (EVSM) principles, called the Digitalized Extended Value Stream Map (DEVSM). Future research on the Digital Extended Value Stream Map (DEVSM) will focus on further refining and detailing the conceptual model to enhance its applicability across various industries. This includes a deeper exploration of key components, data integration mechanisms, and the role of advanced analytics in optimizing supply chain performance. Also, there will be a chance to explore and put KPIs to be able to measure the supply chain model's performance. Additionally, simulation tools can be used to test and validate DEVSM's effectiveness in different supply chain scenarios, providing insights into potential improvements and real-world applicability. Future studies can also explore practical implementation strategies, assessing how DEVSM can be integrated into existing supply chain frameworks. By bridging the gap between theory and practice, these advancements will contribute to the ongoing digital transformation of supply chains, ensuring greater efficiency, resilience, and collaboration across value networks.

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