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INTEGRATING IOT AND BIG DATA ANALYTICS FOR ENHANCED SUPPLY CHAIN PERFORMANCE IN INDUSTRIAL ENGINEERING SECTORS: A CROSS-MARKET STUDY

***Md Abu Taher*[1], *Md Arafat Sikder*[2], *Hasib Ahmed*[3], *Mahboob Al Bashar*[4],**

[1]*Cullen College of Engineering, Industrial Engineering, University of Houston, Houston, Texas, US*

[2]*College of Engineering, Industrial and System Engineering, Lamar University, Beaumont, Texas, US*

[3]*College of Engineering, Industrial and System Engineering, Lamar University, Beaumont, Texas, US*

[4]*Cullen College of Engineering, Industrial Engineering, University of Houston, Houston, Texas, US*

Keywords

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ABSTRACT

Integrating the Internet of Things (IoT) and big data analytics revolutionizes supply chain management across industrial engineering sectors, offering unprecedented opportunities for enhancing efficiency, responsiveness, and competitive advantage. This study employs a qualitative research design, leveraging expert interviews to explore the multifaceted impact of these technologies on supply chain performance. Findings underscore the critical importance of strategic alignment, leadership support, and a clear focus on business objectives for successful technology implementation. Enhanced real-time visibility, improved decision-making, and operational efficiency are identified as consistent benefits across sectors. However, the specific outcomes and applications vary according to industry-specific challenges and priorities. Despite the rich insights gained, the study acknowledges the limitations inherent in its qualitative approach. It suggests avenues for future research, including quantitative analyses and deeper dives into sector-specific implementations. This research contributes to a better understanding of how IoT and big data analytics can be effectively integrated into supply chains, providing a foundation for organizations seeking to navigate the complexities of digital transformation in an interconnected global marketplace.

1 Introduction

The advent of the Internet of Things (IoT) alongside big data analytics marks a transformative era in industrial engineering, revolutionizing how industries operate and manage their supply chains. IoT, characterized by its network of smart devices equipped with sensors, software, and other technologies, facilitates seamless data collection and exchange (Jayashree et al., 2022). This intricate network enables the monitoring and analysis of operations in real-time, providing a granular view of industrial processes that were previously unattainable (Wang et al., 2016). For instance, sensors placed on machinery can continuously relay data regarding performance, maintenance needs, and operational efficiency. This wealth of information, when processed, offers a foundation for optimizing workflows, enhancing productivity, and minimizing downtime. As industries increasingly adopt IoT technologies, the ability to gather comprehensive datasets across various facets of the manufacturing and supply chain processes significantly alters the landscape of industrial engineering, setting the stage for advanced operational intelligence and efficiency (Al Bashar et al., 2024). According to Tiwari et al. (2018), in parallel, big data analytics is a pivotal complement to IoT, providing the analytical horsepower needed to decipher the vast arrays of data generated by interconnected devices. This analytical domain encompasses a range of techniques and methodologies designed to parse through large volumes of complex data to unearth patterns, trends, and insights that are not immediately obvious. Integrating big data analytics into industrial operations facilitates transitioning from traditional, intuition-based decision-making to an environment where data-driven insights inform decisions (Bari, 2023). Such an environment leverages predictive analytics to forecast future trends, prescriptive analytics to recommend optimal decisions, and descriptive analytics to provide a historical overview of operations. By harnessing these insights, industrial engineers can make informed strategic decisions, predicting equipment failures before they occur, optimizing supply chain logistics, and identifying opportunities for process improvements (Teece, 2014; Yadav & Desai, 2017). The synergy between IoT and big data analytics thus heralds a new age of efficiency and innovation in industrial engineering, where data becomes a central pillar of operational strategy (Bag et al., 2018).

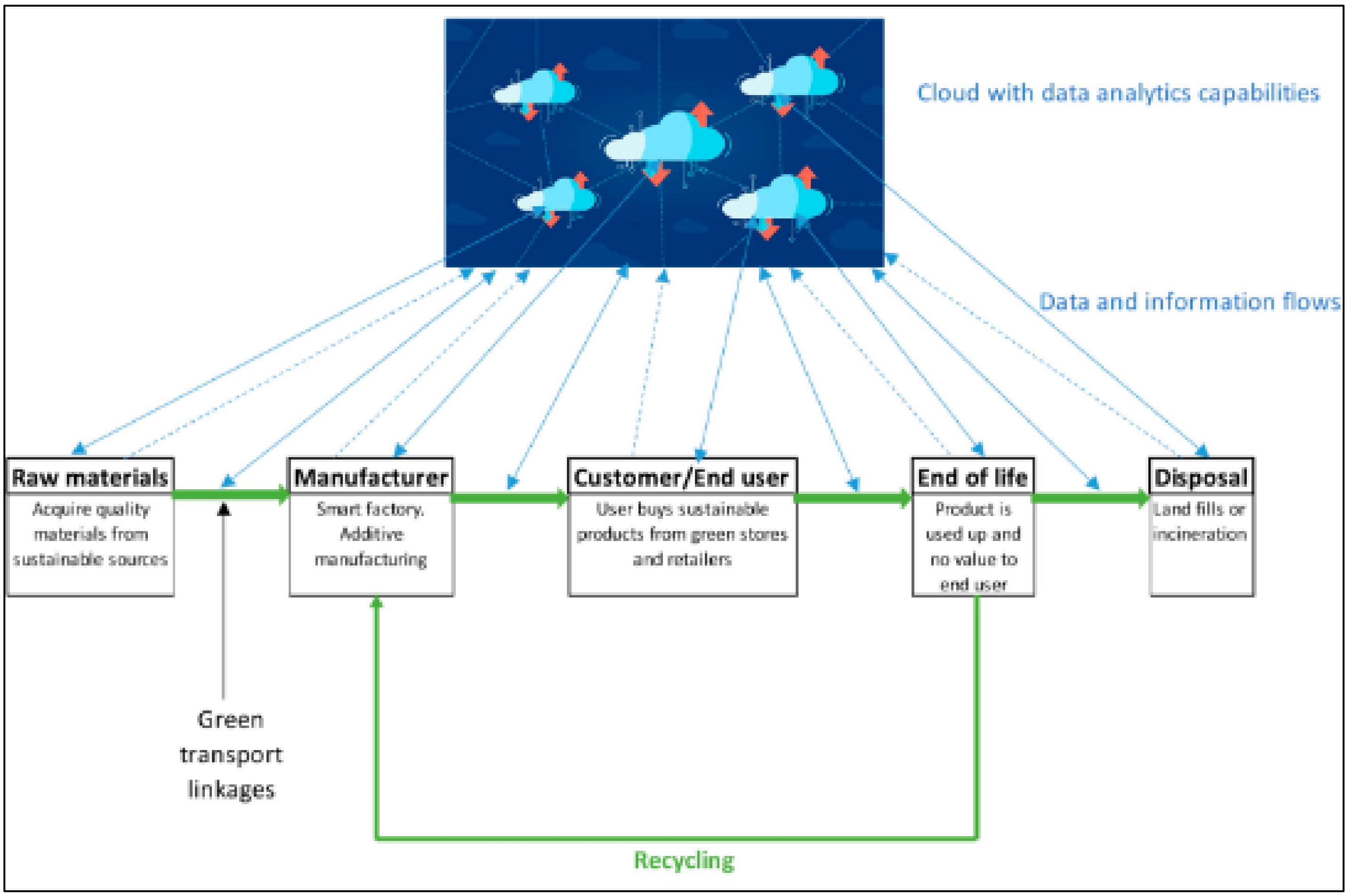

Figure 1: Smart Data Collection Across a Manufacturing Supply Chain
Source: Mageto (2021)

This technological synergy also catalyzes the evolution of supply chain management within the industrial engineering sector (Bag et al., 2018). As IoT devices collect data from every touchpoint in the supply chain (Jayashree et al., 2022), from raw material sourcing to end-product delivery, extensive data analytics processes this information to improve supply chain visibility and coordination. This enhanced oversight enables industries to respond more agilely to market demands, manage inventory more efficiently, and mitigate risks more effectively (Shamsuddoha & Woodside, 2022). Moreover, integrating these technologies facilitates the creation of digital twins—virtual replicas of physical systems—that can simulate supply chain dynamics under various scenarios. This capability allows for testing operational changes and anticipating potential challenges without disrupting processes (Mahbub, 2020; Tiwari et al., 2018). Consequently, the combined force of IoT and big data analytics streamlines existing supply chain operations and paves the way for innovative approaches to supply chain management, embodying a significant leap forward in pursuing operational excellence and sustainability in industrial engineering.

In the contemporary landscape of global commerce, the performance of supply chains across diverse industrial sectors is increasingly challenged by various complex factors (Shamsuddoha & Woodside, 2022). At the heart of these challenges is the issue of limited visibility into the real-time dynamics of supply chains. According to Mahbub (2020), this limitation not only leads to operational inefficiencies but also creates significant obstacles in the path to seizing strategic opportunities. The inability to track and monitor the flow of goods and information in real-time results in a lack of responsiveness to market demands and operational hiccups, diminishing supply chain operations' overall efficacy. Enhanced visibility is crucial for preempting potential disruptions and the smooth execution of supply chain activities, underscoring the need for integrated systems that offer a holistic view of operations (Tiwari et al., 2018). Moreover, the fragmentation of data sources and the prevalence of information silos within organizations further exacerbate the challenges faced by supply chains. This fragmentation hampers seamless communication and collaboration among stakeholders, leading to disjointed and often inefficient supply chain processes. The disparate nature of information flow prevents data aggregation into a coherent whole, making it difficult for supply chain managers to formulate cohesive strategies (Zhong et al., 2016). This situation is further complicated by the rapid pace at which data is generated and the diverse formats in which it exists, posing significant challenges to data management and utilization. Effective integration of data sources and breaking down of information silos are imperative for enhancing coordination, improving decision-making, and ultimately achieving a competitive advantage in the market (Yadav & Desai, 2016; Yadav et al., 2017a).

Additionally, the exponential growth in the volume of data produced by modern supply chains presents its challenges (Wang et al., 2016). The sheer scale and complexity of this data overwhelm traditional data processing tools and methodologies, limiting the ability of businesses to extract meaningful insights. This bottleneck impedes supply chains' agility and adaptability, making it difficult to predict trends, anticipate potential disruptions, and adjust operations proactively (Ghadimi et al., 2019; Mangla et al., 2020). The need for advanced analytics and sophisticated data processing capabilities is more critical than ever, as these tools can enable organizations to navigate the complexities of modern supply chains, enhance operational efficiency, and foster a more anticipatory approach to managing supply chain risks. Developing robust analytical frameworks and investing in cutting-edge technologies are essential steps toward overcoming these challenges and unlocking the full potential of supply chain performance (Karmaker et al., 2023). This cross-market study is poised to embark on a comprehensive examination of the transformative impact that the integration of the Internet of Things (IoT) and big data analytics can have on supply chain performance across a variety of industrial sectors. At the forefront of this investigation is the objective to discern and evaluate the key performance indicators (KPIs) most significantly affected by adopting these advanced technologies.

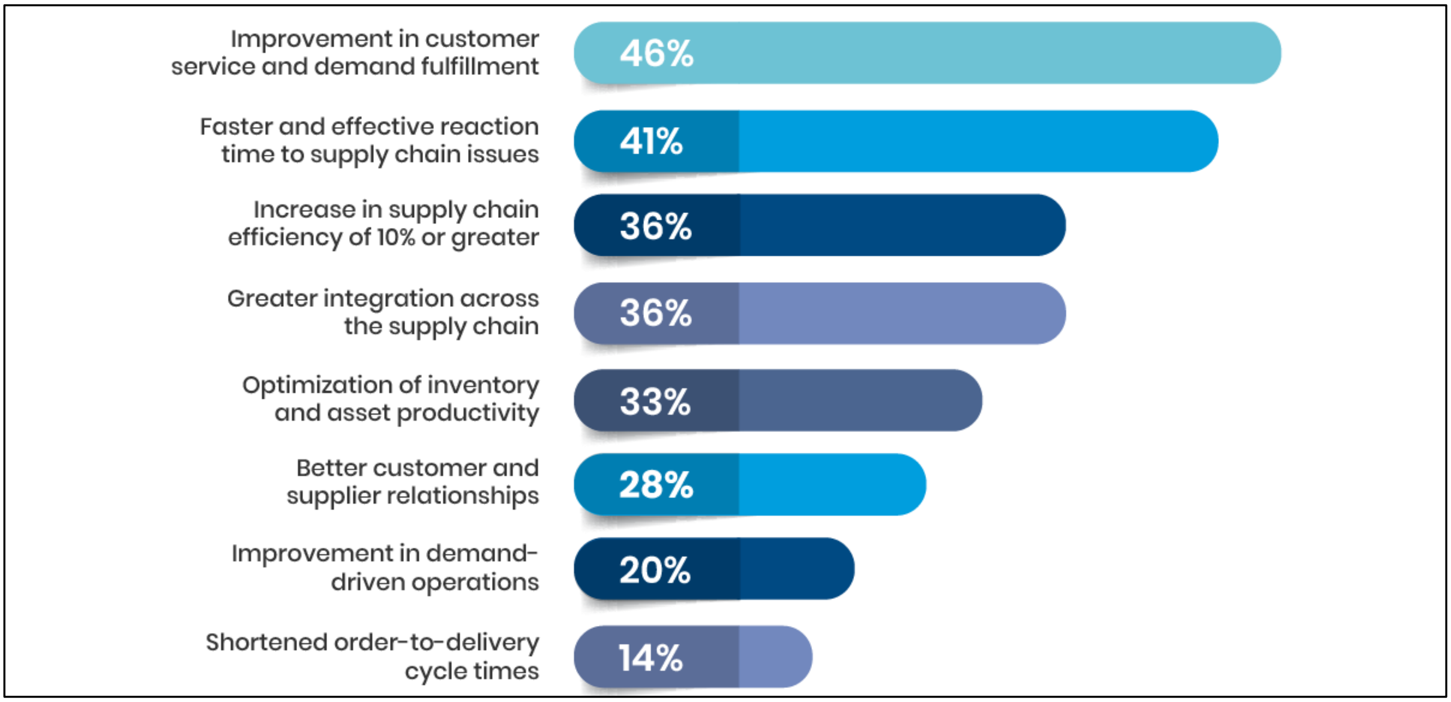

Figure 2: How Big Data Analytics is Benefiting Supply Chain Busines

Source: OodlessERP (2024)

The study aims to provide a nuanced understanding of how IoT and big data analytics can influence operational efficiency, cost reduction, customer satisfaction, and supply chain performance by pinpointing these critical metrics (Kabir & Ekici, 2024). This endeavor will involve a meticulous analysis of various industrial contexts to identify the KPIs that serve as benchmarks for success, thereby facilitating a targeted approach to technology implementation. Another critical aspect of this study involves mapping IoT and big data applications across diverse industrial landscapes (Bhuiyan et al., 2021; Das et al., 2023). This exploration aims to uncover the specific use cases where these technologies have been deployed to address unique challenges and pain points inherent to different sectors. By cataloging these applications, the research aims to showcase the versatility and adaptability of IoT and big data analytics in enhancing supply chain operations, whether improving inventory management, enhancing real-time tracking and monitoring, or optimizing resource allocation (Ahamed et al., 2023; Ahmed et al., 2021). This comprehensive mapping will not only highlight successful implementations but also shed light on the scalability and replicability of such solutions across various industrial settings. Furthermore, the study is set to undertake a thorough assessment of both the benefits and the challenges that accompany the integration of IoT and big data analytics within supply chains (Datta et al., 2024). This dual analysis is crucial for providing a balanced perspective on the adoption of these technologies, acknowledging the significant advantages they offer in terms of increased visibility, predictive capabilities, and decision-making support while also considering the hurdles such as data security concerns, technological complexity, and the need for skilled personnel (Cannavacciuolo et al., 2023). Alongside this evaluation, the study aims to develop a set of best practices and actionable recommendations that can guide industrial engineering domains in successfully leveraging IoT and big data analytics. These guidelines will be crafted to optimize supply chain performance, drawing from the insights gained through the cross-market analysis and addressing the strategic and operational dimensions of technology integration (Ahmed et al., 2021).

2 Literature Review

The burgeoning convergence of the Internet of Things (IoT) and big data analytics has ushered in a new era for supply chain management, marked by enhanced efficiency, transparency, and strategic decision-making capabilities. Karmaker et al. (2023) underscore the transformative potential of IoT networks in capturing real-time data across the entirety of the supply chain, facilitating a level of visibility that was previously unattainable. This granular, real-time data acquisition paves the way for more informed and dynamic management practices, allowing for the meticulous monitoring of goods, machinery, and environmental conditions at every stage of the supply chain. Concurrently Datta et al. (2024) highlight how big data analytics is the key to unlocking the immense value buried within vast datasets generated by IoT devices. Through sophisticated analytical techniques, businesses can distill actionable insights, forecast future trends, and make data-driven decisions that significantly optimize supply chain operations. The literature further elucidates the symbiotic relationship between IoT and big data analytics, emphasizing their collective role in advancing supply chain management towards a more predictive and proactive paradigm. Studies have shown that integrating these technologies enhances operational efficiencies, mitigating risks, reducing costs, and improving customer satisfaction. For instance, predictive analytics derived from big data can accurately forecast demand fluctuations and supply chain disruptions, enabling companies to adjust their strategies in real time (Bhuiyan et al., 2021; Chawla & Kumar, 2023). This proactive approach to supply chain management underscores the shift from traditional, reactive models to anticipatory ones, driven by the wealth of data and insights provided by IoT and big data analytics. However, the literature also points to challenges and considerations in harnessing the full potential of IoT and big data analytics within supply chain management (Ahamed et al., 2023; Debnath et al., 2023). Data privacy, security, and the integration of disparate data systems pose significant hurdles to the widespread adoption of these technologies (Wu & Dunn, 1995). Moreover, the need for specialized skills and a deep understanding of data analytics is often cited as a critical barrier to practical implementation. Despite these challenges, the consensus among researchers is clear: the strategic integration of IoT and big data analytics is critical to revolutionizing supply chain management, offering unprecedented opportunities for optimization, resilience, and competitive advantage. The ongoing exploration of this integration within the academic community is crucial for overcoming existing barriers and unlocking these technologies' full benefits (Wood et al., 2016).

Integrating the Internet of Things (IoT) and big data analytics into supply chain management (SCM) is a topic that has garnered considerable attention in recent literature, highlighting the transformative potential of these technologies. Studies by (Wamba et al., 2017); Yadav et al. (2017b) have shown that IoT-enabled inventory management systems significantly reduce stockouts and improve inventory accuracy. By providing real-time data on inventory levels, these systems enable more accurate demand forecasting, thereby enhancing supply chain efficiency. Additionally, research by Wood et al. (2018) emphasizes the role of IoT in improving product traceability. This capability is critical for ensuring consumer safety and supporting initiatives like product recalls and verification of ethical sourcing practices, thereby adding a layer of transparency and trust to SCM. Moreover, the application of big data analytics in SCM, as discussed by Telukdarie et al. (2018), has been instrumental in extracting actionable insights from the vast amounts of data generated by IoT devices. This analysis facilitates pattern identification and predictive modeling, which is crucial for evidence-based decision-making and optimization of supply chain processes. For instance, Teece (2014) highlight using IoT data combined with machine learning algorithms to predict equipment failures, enabling proactive maintenance strategies that minimize downtime and optimize resource allocation. Such predictive capabilities are fundamental in transitioning from reactive to proactive SCM.

The impact of IoT and big data analytics is equally profound in logistics. Tao et al. (2017) illustrate how these technologies can revolutionize logistics operations through dynamic route planning and real-time fleet management. Companies can significantly reduce costs and improve delivery times by leveraging IoT for real-time tracking and big data analytics to optimize shipping routes. This synergy between IoT and big data enhances operational efficiency and contributes to sustainability by reducing fuel consumption and emissions. Thus, the literature consistently underscores the pivotal role of IoT and big data analytics in driving innovation and efficiency across all facets of supply chain management, marking a paradigm shift towards more integrated, transparent, and responsive supply chain systems.

According to Sivarajah et al. (2017), Integrating the Internet of Things (IoT) and big data analytics has emerged as a critical driver of efficiency and innovation within supply chain management, offering capabilities that enhance visibility, improve operational agility, and enable data-driven decision-making. Olugu et al. (2011) highlight the role of IoT in capturing real-time data across the supply chain, which, when analyzed through big data analytics, can lead to substantial reductions in operational costs. This synergy facilitates a level of process optimization previously unattainable, allowing for the dynamic adjustment of operations to meet market demands efficiently. Similarly, Hu et al. (2019) emphasize the impact of these technologies on reducing lead times, a crucial factor for industries where time sensitivity directly correlates with customer satisfaction and market competitiveness. By streamlining procurement and production processes, organizations can significantly shorten the cycle from production to delivery, enhancing their responsiveness to customer needs. Moreover, the strategic application of IoT and big data analytics has proven to significantly bolster customer satisfaction, a pivotal aspect of supply chain performance. Lun (2011) argue that the real-time insights IoT devices provide and the predictive power of big data analytics can transform supply chain responsiveness. This transformation is not merely operational but extends to how companies anticipate and fulfill customer expectations, delivering personalized experiences and ensuring reliability in delivery schedules (Ali et al., 2023; Teece, 2014). Enhanced customer satisfaction directly translates into improved brand loyalty and a stronger competitive position in the marketplace.

3 Theoretical Framework

In exploring the theoretical underpinnings of IoT and big data analytics within the realm of supply chain management, the Resource-Based View (RBV) emerges as a compelling framework for understanding the strategic value of these technologies. According to RBV, competitive advantage is gained through acquiring and exploiting valuable, rare, inimitable, and non-substitutable resources (Barney & Tyler, 1991). In this context, the data streams generated by IoT devices are characterized as unique resources that are valuable for their real-time insight and difficult for competitors to replicate. This perspective is supported by Soo et al. (2023), who argue that IoT-generated data enhances decision-making capabilities, offering companies a distinctive edge in the competitive landscape. The RBV framework thus provides a theoretical rationale for the strategic integration of IoT technologies in supply chains, emphasizing the role of unique resources in achieving and sustaining competitive advantages.

Furthermore, applying systems theory to supply chain management offers additional insights into how IoT and big data analytics contribute to overall supply chain performance. Systems theory, which views organizations as complex sets of interconnected components working together to achieve specific objectives, underscores the importance of seamless information flow and coordination among all parts of the supply chain (Ocelík et al., 2023). Taelman et al. (2019) highlight how IoT-enabled real-time visibility facilitates a more integrated and responsive supply chain ecosystem. By providing instant access to information across all nodes, IoT technologies enable supply chain partners to synchronize their operations more effectively, respond swiftly to disruptions, and continuously refine processes for optimal efficiency. This theoretical perspective reinforces that IoT's systemic integration can enhance supply chain coherence and agility, aligning with systems theory principles by promoting interconnectivity and mutual dependency among components. The synthesis of RBV and systems theory in the context of IoT and big data analytics within supply chains illuminates the multifaceted benefits of these technologies. While RBV focuses on strategically acquiring and utilizing valuable resources for competitive advantage, systems theory emphasizes the operational efficiencies gained through enhanced coordination and information sharing. Together, these theoretical frameworks provide a comprehensive understanding of how IoT and big data analytics can transform supply chain management. They suggest that the strategic value of IoT-generated data, coupled with the operational improvements from increased visibility and coordination, enhances supply chain performance and contributes to a sustainable competitive advantage. This theoretical groundwork sets the stage for further empirical investigation into the specific mechanisms through which IoT and significant data analytics drive improvements in supply chain operations, offering a robust foundation for future research and practice in the field (Ahmed et al., 2021).

In the supply chain management realm, the dynamic capability view (DCV) application sheds light on how organizations can leverage IoT and big data analytics to enhance their adaptability and responsiveness to market changes. The DCV posits that in today's volatile business environment, the ability of an organization to reconfigure its operational processes and resources dynamically is crucial for sustaining competitive advantage (Barney & Tyler, 1991). IoT technologies facilitate the real-time collection of vast amounts of data from various points in the supply chain. At the same time, big data analytics enables the extraction of valuable insights from this data. Together, they empower organizations to swiftly adjust their supply chain strategies in response to emerging trends, disruptions, or opportunities, exemplifying the essence of dynamic capabilities. Moreover, the principles of lean management theory complement the insights provided by the DCV, particularly in integrating IoT and big data analytics into supply chain operations. Lean management eliminates waste and optimizes value-creation processes to enhance performance (Atolia et al., 2020). The deployment of IoT devices across the supply chain generates a continuous stream of data, highlighting areas of inefficiency and waste. When this data is analyzed through big data analytics, it unveils patterns and insights that guide the elimination of non-value-adding activities and the optimization of resources. This synergistic application of IoT and big data analytics aligns with lean theory’s emphasis on waste reduction and value maximization, driving the pursuit of operational excellence in supply chain management. Integrating IoT and big data analytics within the supply chain exemplifies the application of dynamic capabilities and lean management principles. It represents a paradigm shift in how organizations approach supply chain optimization (Daxini et al., 2019). By harnessing the power of real-time data and analytics, firms can anticipate changes, mitigate risks, and seize opportunities with unprecedented speed and precision. This evolution underscores the importance of a theoretical framework that embraces both the dynamic capability view and lean management principles, offering a comprehensive understanding of the mechanisms through which IoT and big data analytics catalyze performance improvements in supply chains. The continued exploration of these frameworks in the context of modern supply chain challenges highlights the need for innovative strategies that leverage technological advancements to foster agility, efficiency, and sustainable competitive advantage (Cannavacciuolo et al., 2023; Luthra & Mangla, 2018).

A comprehensive literature review should synthesize existing findings and propose novel directions for future research. Current sector-specific models for IoT deployment (e.g., manufacturing, healthcare) illustrate the technology's potential, yet a more generalized framework emphasizing adaptability across various industrial engineering sectors is needed. Such a model necessitates addressing both technical components (sensor selection, data standardization, analytics methodologies) and the organizational implications of change (Bhuiyan et al., 2021). The socio-technical systems approach, emphasizing the critical interplay between technology and organizational transformation, offers a promising foundation for such a model (Zhan et al., 2016). An integrative model informed by this perspective would facilitate successful implementation and broad adoption of IoT and big data analytics.

4 Methodology

A qualitative research methodology centered around expert interviews was employed to understand how IoT and big data analytics are reshaping supply chain performance across different industrial sectors. This approach aligns with recommendations in the literature to employ qualitative methods, such as interviews, for in-depth exploration of real-world practices. Each expert, selected for their significant contributions to fields as varied as manufacturing, logistics, and healthcare,

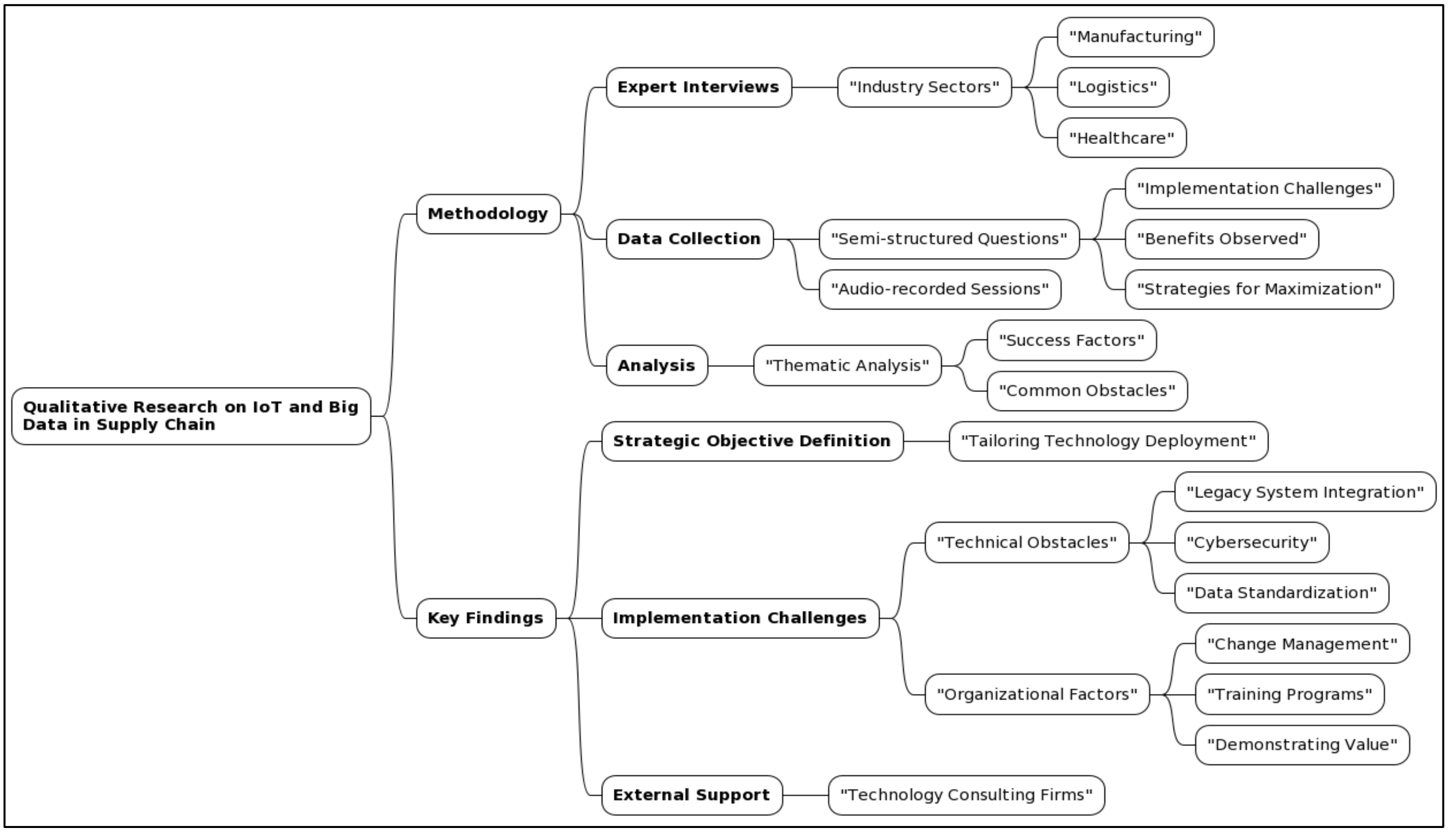

Figure 3: Summary of the Method implemented for this study

provided a unique perspective on the role of IoT and big data in enhancing supply chain dynamics. The interview process was designed to facilitate an open dialogue, encouraging participants to share their experiences with IoT and big data analytics within their respective sectors. This approach allowed for collecting in-depth qualitative data, shedding light on the complexities of adopting IoT and big data analytics in diverse operational contexts. Detailed notes were taken during each interview, and, with the consent of the participants, sessions were audio-recorded to ensure accuracy in data capture and to facilitate a thorough analysis (Atolia et al., 2020). This comprehensive analysis highlighted best practices and innovative approaches to leveraging IoT and big data analytics for supply chain optimization, directly informed by industry leaders' expertise and real-world experiences (Ahamed et al., 2023; Wood et al., 2018). Interviews with experts across diverse industries provide firsthand knowledge about successful IoT and big data analytics implementations within supply chains. A common theme in the literature emphasizes the importance of clearly defining strategic objectives before technology selection. Experts stress that a deep understanding of specific pain points or desired performance outcomes is necessary to shape a solution that delivers tangible value. This underscores the need to tailor technology deployment to sector-specific needs. While the potential benefits are widely acknowledged, expert interviews consistently highlight challenges encountered during IoT/significant data analytics implementation. Experts further point out that organizational factors are critical in successful adoption. Interview findings often emphasize the value of seeking external support from experienced technology consulting firms to complement in-house capabilities, especially in resource-constrained contexts.

5 Discussion

Through a qualitative analysis grounded in expert interviews, it becomes evident that the cornerstone of effective integration of IoT and big data analytics within industrial engineering sectors lies in the principle of strategic alignment. As articulated by Bhuiyan et al. (2021) and echoed by Daxini et al. (2019), the deployment of these advanced technologies must be underpinned by a clear and coherent strategy that aligns with the overarching goals of supply chain improvement. This strategic alignment ensures that technology adoption is purposeful and directed towards achieving specific outcomes such as enhanced operational efficiency, improved customer satisfaction, and increased agility in response to market changes. It steers organizations away from the pitfalls of adopting technology for its own sake and towards a path where technology serves as a lever for achieving strategic objectives, thereby maximizing the value of investments in IoT and big data analytics. The role of leadership in the successful adoption and integration of IoT and big data analytics emerges as a critical factor, as consistently highlighted across the interviews. The study by Cannavacciuolo et al. (2023) reinforce that leadership buy-in and active sponsorship are indispensable for accelerating technology integration. Leadership commitment is crucial for allocating necessary resources and fostering a culture of collaboration and innovation that supports implementation efforts. This top-down support is instrumental in surmounting potential obstacles, such as resistance to change, which can derail technology adoption initiatives. By championing the cause and demonstrating unwavering support, leaders can mobilize the organization towards embracing new technologies, ensuring a smoother transition and more effective integration of IoT and big data analytics into the supply chain processes (Cannavacciuolo et al., 2023).

Furthermore, the interviews shed light on the multifaceted challenges of integrating IoT and big data analytics. These challenges span technical and organizational domains, necessitating a comprehensive approach to address them effectively. Technical challenges include data integration, cybersecurity, and ensuring the reliability and scalability of IoT devices and systems. At the same time, organizational challenges include managing change, cultivating the necessary skills and competencies among the workforce, and aligning the organizational culture with new technological paradigms. Addressing these challenges requires a concerted effort to combine technical solutions with organizational development and change management strategies. This holistic approach facilitates the successful adoption of IoT and big data analytics and their sustained impact on enhancing supply chain performance within the industrial engineering sectors. The aggregation of insights from industry experts delineates the transformative impact of IoT and big data analytics on enhancing supply chain visibility across diverse industrial engineering sectors. As highlighted in the studies by Jayashree et al. (2022), the deployment of IoT technologies enables the capture and real-time monitoring of data across the entire supply chain, marking a significant shift toward transparency and operational clarity. This leap in visibility facilitates a more informed decision-making process, allowing for swift adjustments in response to emerging disruptions or changes in demand. Furthermore, the seamless flow of real-time information fosters enhanced collaboration among supply chain partners, breaking down traditional information sharing and coordination barriers. The consensus among experts underscores the notion that improved visibility is a technological achievement and a strategic asset that drives more cohesive and agile supply chain operations. Operational efficiency is another critical benefit of integrating IoT and big data analytics, with experts acknowledging its substantial role in streamlining supply chain processes. According to Bhuiyan et al. (2021), the analytical prowess of big data, combined with the extensive sensory network of IoT, enables a granular analysis of operations, uncovering previously obscured inefficiencies. This detailed insight into operational dynamics leads to identifying and eliminating wasteful practices, significantly reducing lead times and operational costs while optimizing resource allocation.

The capacity to pinpoint and rectify inefficiencies boosts overall supply chain performance. It contributes to a leaner, more responsive operational model that can swiftly adapt to market demands or operational challenges.

The findings of this study offer a compelling demonstration of the interplay between theoretical models and real-world implementation of IoT and big data analytics. Consistent with the resource-based view (RBV), experts emphasize how IoT-generated real-time data can be leveraged as a unique and valuable strategic asset (Daxini et al., 2019). As stressed in the interviews, leadership sponsorship and strategic alignment embody the concept of dynamic capabilities, facilitating the organizational agility required to thrive in a rapidly evolving landscape (Sancho et al., 2018). Additionally, the cross-sector improvement in supply chain visibility resonates with systems theory principles. This underscores the interconnected nature of supply chain elements and the potential for systemic optimization through seamless information flow (Zhan et al., 2016). The insights gained from these interviews point towards a fundamental transformation in supply chain strategies and operations, with IoT and big data analytics serving as catalysts. The ability to shift from reactive to proactive approaches, as emphasized by experts, is a paradigm shift. Predictive analytics informed by IoT data redefine maintenance strategies in manufacturing, minimizing costly unplanned downtime (Bag, 2017). Furthermore, fostering a data-driven culture enables evidence-based decision-making across the organization, ensuring the optimal allocation of resources and supporting a continuous improvement mindset aligned with lean theory principles (Gunasekaran et al., 2017). The capacity to redefine customer service standards through real-time trackability and proactive issue resolution has significant implications for building trust and competitive advantage (Hazen et al., 2014). The findings hold significant implications for practitioners and policymakers within industrial engineering sectors. Practitioners must prioritize change management and executive buy-in, recognizing that successful implementation extends beyond technical considerations and into organizational culture. Policymakers should proactively support initiatives facilitating reskilling and workforce development to ensure organizations can harness the full potential of IoT and big data analytics (Soo et al., 2023). Additionally, investment in robust data infrastructure and the development of comprehensive cybersecurity standards is essential. This aligns with expert concerns and is vital for establishing trust within increasingly interconnected and data-driven supply chains (Wang et al., 2016).

6 Conclusion

This study elucidates the profound impact of integrating IoT and big data analytics within supply chains across varied industrial engineering sectors, highlighting the necessity of strategic alignment, leadership involvement, and transparent business goals for effective implementation. The consistent emergence of benefits such as real-time visibility, improved decision-making capabilities, and heightened operational efficiency underscores these technologies' significant potential for addressing critical supply chain challenges and fostering competitive advantage. However, while offering in-depth contextual understanding, the study's reliance on expert interviews suggests a need for future research to incorporate quantitative performance metrics and delve into sector-specific intricacies to provide more granular recommendations. Additionally, examining the long-term impact of these technologies on evolving supply chain models could further enrich our understanding and application of IoT and big data analytics. As organizations navigate the complexities of technological adoption, emphasizing organizational flexibility and a commitment to leveraging data for strategic decisions will be paramount. Embracing these changes positions companies to capitalize on unprecedented efficiency gains and operational optimization, marking a significant step forward in the continuous evolution of global supply chains.

References:

Ahamed, M. S., Sultan, M., Shamshiri, R. R., Rahman, M. M., Aleem, M., & Balasundram, S. K. (2023). Present status and challenges of fodder production in controlled environments: A review. *Smart Agricultural*

Technology, *3*, 100080. https://doi.org/https://doi.org/10.1016/j.atech.2022.100080

Ahmed, M., Bashar, I., Alam, S. T., Wasi, A. I., Jerin, I., Khatun, S., & Rahman, M. (2021). An overview of Asian cement industry: Environmental impacts, research methodologies and mitigation measures. *Sustainable Production and Consumption*, *28*, 1018-1039. https://doi.org/https://doi.org/10.1016/j.spc.2021.07.024

Al Bashar, M., Taher, M. A., Islam, M. K., & Ahmed, H. (2024). The Impact Of Advanced Robotics And Automation On Supply Chain Efficiency In Industrial Manufacturing: A Comparative Analysis Between The Us And Bangladesh. *Global Mainstream Journal of Business, Economics, Development & Project Management*, *3*(03), 28-41.

Ali, M. A., Dhanaraj, R. K., & Nayyar, A. (2023). A high performance-oriented AI-enabled IoT-based pest detection system using sound analytics in large agricultural field. *Microprocessors and Microsystems*, *103*, 104946. https://doi.org/https://doi.org/10.1016/j.micpro.2023.104946

Atolia, M., Loungani, P., Marquis, M., & Papageorgiou, C. (2020). Rethinking development policy: What remains of structural transformation? *World Development*, *128*, 104834. https://doi.org/https://doi.org/10.1016/j.worlddev.2019.104834

Bag, S. (2017). Big Data and Predictive Analysis is Key to Superior Supply Chain Performance: A South African Experience. *International Journal of Information Systems and Supply Chain Management*, *10*(2), 66-84. https://doi.org/10.4018/ijisscm.2017040104

Bag, S., Gupta, S., & Telukdarie, A. (2018). Importance of innovation and flexibility in configuring supply network sustainability. *Benchmarking: An International Journal*, *25*(9), 3951-3985. https://doi.org/10.1108/bij-06-2017-0132

Bari, M. H. (2023). Analysing The Impact Of Technology Adoption On Efficiency In Us Wholesale And Distribution: A Comprehensive Review Of Analytical Strategies. *Global Mainstream Journal of Business, Economics, Development & Project Management*, *2*(04), 27-39.

Barney, J., & Tyler, B. (1991). The prescriptive limits and potential for applying strategic management theory. *Managerial and Decision Economics*, *17*(1), 99-120.

Bhuiyan, E. A., Hossain, M. Z., Muyeen, S. M., Fahim, S. R., Sarker, S. K., & Das, S. K. (2021). Towards next generation virtual power plant: Technology review and frameworks. *Renewable and Sustainable Energy Reviews*, *150*, 111358. https://doi.org/https://doi.org/10.1016/j.rser.2021.111358

Cannavacciuolo, L., Ferraro, G., Ponsiglione, C., Primario, S., & Quinto, I. (2023). Technological innovation-enabling industry 4.0 paradigm: A systematic literature review. *Technovation*, *124*, 102733. https://doi.org/https://doi.org/10.1016/j.technovation.2023.102733

Chawla, I., & Kumar, N. (2023). FDI, international trade and global value chains (GVCs): India's GVC participation, position and value capture. *Asia and the Global Economy*, *3*(2), 100071. https://doi.org/https://doi.org/10.1016/j.aglobe.2023.100071

Das, S. K., Benkhelifa, F., Sun, Y., Abumarshoud, H., Abbasi, Q. H., Imran, M. A., & Mohjazi, L. (2023). Comprehensive review on ML-based RIS-enhanced IoT systems: basics, research progress and future challenges. *Computer Networks*, *224*, 109581. https://doi.org/https://doi.org/10.1016/j.comnet.2023.109581

Datta, S. D., Islam, M., Rahman Sobuz, M. H., Ahmed, S., & Kar, M. (2024). Artificial intelligence and machine learning applications in the project lifecycle of the construction industry: A comprehensive review. *Heliyon*, *10*(5), e26888. https://doi.org/https://doi.org/10.1016/j.heliyon.2024.e26888

Daxini, A., Ryan, M., O'Donoghue, C., Barnes, A., & Buckley, C. (2019). Using a typology to understand farmers' intentions towards following a nutrient management plan. *Resources, Conservation and Recycling*, *146*(NA), 280-290. https://doi.org/10.1016/j.resconrec.2019.03.027

Debnath, B., Shakur, M. S., Bari, A. B. M. M., & Karmaker, C. L. (2023). A Bayesian Best–Worst approach for assessing the critical success factors in sustainable lean manufacturing. *Decision Analytics Journal*, *6*, 100157. https://doi.org/https://doi.org/10.1016/j.dajour.2022.100157

Ghadimi, P., Wang, C., & Lim, M. K. (2019). Sustainable supply chain modeling and analysis: Past debate, present problems and future challenges. *Resources, Conservation and Recycling*, *140*(NA), 72-84. https://doi.org/10.1016/j.resconrec.2018.09.005

Gunasekaran, A., Papadopoulos, T., Dubey, R., Wamba, S. F., Childe, S. J., Hazen, B. T., & Akter, S. (2017). Big data and predictive analytics for supply chain and organizational performance. *Journal of Business Research*, *70*(NA), 308-317. https://doi.org/10.1016/j.jbusres.2016.08.004

Hazen, B. T., Boone, C. A., Ezell, J. D., & Jones-Farmer, L. A. (2014). Data quality for data science, predictive analytics, and big data in supply chain management: An introduction to the problem and suggestions for research and applications. *International Journal of Production Economics*, *154*(NA), 72-80. https://doi.org/10.1016/j.ijpe.2014.04.018

Hu, J., Liu, Y.-L., Yuen, T. W. W., Lim, M. K., & Hu, J. (2019). Do green practices really attract customers? The sharing economy from the sustainable supply chain management perspective. *Resources, Conservation and Recycling*, *149*(NA), 177-187. https://doi.org/10.1016/j.resconrec.2019.05.042

Jayashree, S., Reza, M. N. H., Malarvizhi, C. A. N., Gunasekaran, A., & Rauf, M. A. (2022). Testing an adoption model for Industry 4.0 and sustainability: A Malaysian scenario. *Sustainable Production and Consumption*, *31*, 313-330. https://doi.org/https://doi.org/10.1016/j.spc.2022.02.015

Kabir, M., & Ekici, S. (2024). Energy-agriculture nexus: Exploring the future of artificial intelligence applications. *Energy Nexus*, *13*, 100263. https://doi.org/https://doi.org/10.1016/j.nexus.2023.100263

Karmaker, C. L., Aziz, R. A., Ahmed, T., Misbauddin, S. M., & Moktadir, M. A. (2023). Impact of industry 4.0 technologies on sustainable supply chain performance: The mediating role of green supply chain management practices and circular economy. *Journal of Cleaner Production*, *419*, 138249. https://doi.org/https://doi.org/10.1016/j.jclepro.2023.138249

Lun, Y. H. V. (2011). Green management practices and firm performance : a case of container terminal operations. *Resources, Conservation and Recycling*, *55*(6), 559-566. https://doi.org/10.1016/j.resconrec.2010.12.001

Luthra, S., & Mangla, S. K. (2018). When strategies matter: Adoption of sustainable supply chain management practices in an emerging economy's context. *Resources, Conservation and Recycling*, *138*(NA), 194-206. https://doi.org/10.1016/j.resconrec.2018.07.005

Mageto, J. (2021). Big Data Analytics in Sustainable Supply Chain Management: A Focus on Manufacturing Supply Chains. *Sustainability*, *13*(13), 7101. https://www.mdpi.com/2071-1050/13/13/7101

Mahbub, M. (2020). Progressive researches on IoT security: An exhaustive analysis from the perspective of protocols, vulnerabilities, and preemptive architectonics. *Journal of Network and Computer Applications*, *168*, 102761. https://doi.org/https://doi.org/10.1016/j.jnca.2020.102761

Mangla, S. K., Kusi-Sarpong, S., Luthra, S., Bai, C., Jakhar, S. K., & Khan, S. A. (2020). Operational excellence for improving sustainable supply chain performance. *Resources, conservation, and recycling*, *162*(NA), 105025-NA. https://doi.org/10.1016/j.resconrec.2020.105025

Ocelík, V., Kolk, A., & Ciulli, F. (2023). Multinational enterprises, Industry 4.0 and sustainability: A multidisciplinary review and research agenda. *Journal of Cleaner Production*, *413*, 137434. https://doi.org/https://doi.org/10.1016/j.jclepro.2023.137434

Olugu, E. U., Wong, K. Y., & Shaharoun, A. M. (2011). Development of key performance measures for the automobile green supply chain. *Resources, Conservation* *and Recycling*, *55*(6), 567-579. https://doi.org/10.1016/j.resconrec.2010.06.003

Sancho, M. P. L., Martínez-Martínez, D., Jorge, M. L., & Madueño, J. H. (2018). Understanding the link between socially responsible human resource management and competitive performance in SMEs. *Personnel Review*, *47*(6), 1211-1243. https://doi.org/10.1108/pr-05-2017-0165

Shamsuddoha, M., & Woodside, A. G. (2022). Achieving radical process innovations by applying technology-mindset transformations via second-order system-dynamics engineering. *Journal of Business Research*, *147*, 37-48. https://doi.org/https://doi.org/10.1016/j.jbusres.2022.04.006

Sivarajah, U., Kamal, M., Irani, Z., & Weerakkody, V. (2017). Critical analysis of Big Data challenges and analytical methods. *Journal of Business Research*, *70*(NA), 263-286. https://doi.org/10.1016/j.jbusres.2016.08.001

Soo, A., Wang, L., Wang, C., & Shon, H. K. (2023). Machine learning for nutrient recovery in the smart city circular economy – A review. *Process Safety and Environmental Protection*, *173*, 529-557. https://doi.org/https://doi.org/10.1016/j.psep.2023.02.065

Taelman, S. E., Sanjuan-Delmás, D., Tonini, D., & Dewulf, J. (2019). An operational framework for sustainability assessment including local to global impacts : focus on waste management systems. *Resources Conservation and Recycling*, *162*(NA), 100005-NA. https://doi.org/NA

Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., & Sui, F. (2017). Digital twin-driven product design, manufacturing and service with big data. *The International Journal of Advanced Manufacturing Technology*, *94*(9), 3563-3576. https://doi.org/10.1007/s00170-017-0233-1

Teece, D. J. (2014). The Foundations of Enterprise Performance: Dynamic and Ordinary Capabilities in an (Economic) Theory of Firms. *Academy of Management Perspectives*, *28*(4), 328-352. https://doi.org/10.5465/amp.2013.0116

Telukdarie, A., Buhulaiga, E., Bag, S., Gupta, S., & Luo, Z. (2018). Industry 4.0 implementation for multinationals. *Process Safety and Environmental Protection*, *118*(NA), 316-329. https://doi.org/10.1016/j.psep.2018.06.030

Tiwari, S., Wee, H.-M., & Daryanto, Y. (2018). Big data analytics in supply chain management between 2010 and 2016: Insights to industries. *Computers & Industrial Engineering*, *115*(NA), 319-330. https://doi.org/10.1016/j.cie.2017.11.017

Wamba, S. F., Gunasekaran, A., Akter, S., Ren, S. J.-f., Dubey, R., & Childe, S. J. (2017). Big data analytics and firm performance: Effects of dynamic capabilities. *Journal of Business Research*, *70*(NA), 356-365. https://doi.org/10.1016/j.jbusres.2016.08.009

Wang, G., Gunasekaran, A., Ngai, E. W. T., & Papadopoulos, T. (2016). Big data analytics in logistics and supply chain management: Certain investigations for research and applications. *International Journal of Production Economics*, *176*(176), 98-110. https://doi.org/10.1016/j.ijpe.2016.03.014

Wood, L. C., Wang, C., Abdul-Rahman, H., & Abdul-Nasir, N. S. J. (2016). Green hospital design: integrating quality function deployment and end-user demands. *Journal of Cleaner Production*, *112*(NA), 903-913. https://doi.org/10.1016/j.jclepro.2015.08.101

Wood, L. C., Wang, J. X., Duong, L. N. K., Reiners, T., & Smith, R. (2018). Stock market reactions to auto manufacturers' environmental failures. *Journal of Macromarketing*, *38*(4), 364-382. https://doi.org/10.1177/0276146718781915

Wu, H. J., & Dunn, S. C. (1995). Environmentally responsible logistics systems. *International Journal of Physical Distribution & Logistics Management*, *25*(2), 20-38. https://doi.org/10.1108/09600039510083925

Yadav, G., & Desai, T. N. (2016). Lean Six Sigma: a categorized review of the literature. *International Journal of Lean Six Sigma*, *7*(1), 2-24. https://doi.org/10.1108/ijlss-05-2015-0015

Yadav, G., & Desai, T. N. (2017). Analyzing Lean Six Sigma enablers: a hybrid ISM-fuzzy MICMAC approach. *The TQM Journal*, *29*(3), 488-511. https://doi.org/10.1108/tqm-04-2016-0041

Yadav, G., Seth, D., & Desai, T. N. (2017a). Analysis of research trends and constructs in context to lean six sigma frameworks. *Journal of Manufacturing Technology Management*, *28*(6), 794-821. https://doi.org/10.1108/jmtm-03-2017-0043

Yadav, G., Seth, D., & Desai, T. N. (2017b). Application of hybrid framework to facilitate lean six sigma implementation: a manufacturing company case experience. *Production Planning & Control*, *29*(3), 185-201. https://doi.org/10.1080/09537287.2017.1402134

Zhan, Y., Tan, K. H., Li, Y., & Tse, Y. K. (2016). Unlocking the power of big data in new product development. *Annals of Operations Research*, *270*(1), 577-595. https://doi.org/10.1007/s10479-016-2379-x

Zhong, R. Y., Newman, S. T., Huang, G. Q., & Lan, S. (2016). Big Data for supply chain management in the service and manufacturing sectors. *Computers & Industrial Engineering*, *101*(101), 572-591. https://doi.org/10.1016/j.cie.2016.07.013