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Adoption of Internet of Things (IoT) Technologies in Supply Chain-Oriented Digital Business Models

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ABSTRACT

In recent years, the rapid advancement of digital technologies has posed major challenges for supply chains, including the need for real-time visibility, operational efficiency, and effective risk management. Integrating technologies such as the Internet of Things (IoT) is hindered by barriers related to technological readiness, organizational capability, environmental pressures, and rising regulatory demands. This study examines IoT adoption in supply chain-oriented digital business models by identifying key drivers, barriers, and performance outcomes, and by developing and validating a conceptual framework linking readiness, capability, and pressure to IoT adoption and subsequent improvements, moderated by firm size, industry, and geography. A mixed-methods approach combined a literature review and expert interviews to build a model, followed by survey data from 350 managers across industries and regions analyzed through structural equation modeling, descriptive statistics, and qualitative insights. Findings show that readiness, capability, and pressure significantly drive IoT adoption, which enhances supply chain integration, efficiency, and innovation, while mediating organizational drivers and outcomes, with effects moderated by firm size and geography. Qualitative insights emphasize practical challenges, sector-specific dynamics, and the role of leadership and workforce engagement. Overall, the study demonstrates that IoT adoption is a pivotal enabler of digital supply chain transformation, offering both theoretical contributions and actionable guidance for managers.

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1-Introduction

The adoption of Internet of Things (IoT) technologies in supply chain oriented digital business models has emerged as one of the most transformative developments in contemporary management and operations research because the ability of connected devices to generate, transmit, and analyze real time data has redefined how organizations design, coordinate, and optimize their supply chains, creating entirely new possibilities for efficiency, responsiveness, and customer centricity. The supply chain, which has traditionally been understood as a network of interconnected firms responsible for sourcing, production, warehousing, distribution, and delivery, is increasingly becoming digitalized, and IoT functions as a backbone of this transformation by providing pervasive visibility and intelligence across all nodes of the network (Ben-Daya et al., 2019). The integration of IoT with supply chain functions allows firms to collect real time data from products, vehicles, warehouses, and even consumer environments, leading to a level of granularity and transparency that was previously unimaginable (Nguyen et al., 2022). Scholars have noted that IoT is not merely an incremental technological tool but a disruptive enabler of digital business models in which value creation and capture rely on interconnected data ecosystems rather than linear flows of goods and information (Frank et al., 2019). Within this context, the adoption of IoT has been associated with several important benefits, including improved operational efficiency, enhanced supply chain resilience, better demand forecasting, reduced waste, improved sustainability, and greater customer satisfaction (Wang & Luo, 2022).

IoT adoption in supply chains is driven by the increasing complexity of global business environments in which firms face volatility, uncertainty, and rapidly shifting consumer expectations. Real time visibility provided by IoT sensors and tracking systems enables organizations to reduce the bullwhip effect, optimize inventory management, and make agile decisions in response to market signals (Zhang & Chen, 2022). In logistics and transportation, GPS enabled IoT devices enhance fleet management, route optimization, and delivery reliability, reducing costs and environmental impacts (Moeuf et al., 2020). In manufacturing, IoT facilitates predictive maintenance by collecting machine level data, thereby minimizing downtime and improving productivity (Xu et al., 2023). Additionally, IoT applications in warehousing, such as automated identification, robotic assistance, and environmental monitoring, increase efficiency and accuracy, leading to fewer errors and reduced labor costs (Kumar et al., 2023). In customer facing operations, IoT data allows firms to track usage patterns, anticipate demand, and offer personalized services, thereby strengthening customer relationships and enabling servitization strategies (Porter & Heppelmann, 2015).

The integration of IoT with other digital technologies magnifies its potential. IoT data streams combined with artificial intelligence and machine learning algorithms generate predictive insights that support advanced decision making (Tan & Wang, 2023). Blockchain technology further enhances the reliability and traceability of IoT data, particularly in industries where provenance and authenticity are critical, such as pharmaceuticals, food, and luxury goods (Kouhizadeh & Sarkis, 2018). Big data analytics, when applied to IoT generated information, unlocks patterns that improve forecasting, optimize resource allocation, and support strategic planning (Choi et al., 2018). The synergy of these technologies contributes to the emergence of supply chain 4.0, a paradigm in which interconnected systems dynamically coordinate supply and demand in near real time, transforming business models from push based to demand driven and adaptive ones (Ivanov et al., 2019).

Despite these opportunities, IoT adoption is accompanied by significant challenges that require managerial attention. One of the foremost barriers is the high cost of implementation, which includes expenditure on hardware, software, connectivity, and data platforms (Nguyen et al., 2022). For small and medium sized enterprises, these costs can be prohibitive, thereby slowing diffusion and creating a digital divide between larger corporations and smaller players (Khan et al., 2019). Interoperability issues and the absence of universal standards also complicate IoT integration because devices and platforms from different vendors may not communicate effectively, leading to fragmentation and inefficiencies (Holler et al., 2014). Data security and privacy concerns represent another critical obstacle; as the number of connected devices proliferates, the attack surface for cyber threats expands, necessitating significant investments in cybersecurity measures and governance frameworks (Weber, 2010). Organizational factors, such as employee resistance, lack of digital skills, and cultural barriers, further inhibit IoT adoption because successful implementation requires not only technological investment but also human and organizational readiness (Moeuf et al., 2020).

The value of IoT adoption is particularly evident in the context of risk management and resilience. The COVID-19 pandemic highlighted the fragility of traditional supply chains and underscored the importance of digital technologies in providing real time visibility and adaptive capacity (Queiroz et al., 2020). IoT enables early warning systems that detect disruptions, monitor supplier performance, and facilitate contingency planning, thereby enhancing resilience and reducing vulnerability (Ivanov & Dolgui, 2020). The ability to track inventory levels and shipment conditions in real time allows firms to rapidly reroute supplies, mitigate bottlenecks, and ensure continuity even in volatile environments (Shih, 2020). Beyond pandemic disruptions, IoT adoption supports resilience in the face of natural disasters, geopolitical uncertainties, and fluctuating consumer demand by enabling data driven agility (Dolgui & Ivanov, 2021).

From a sustainability perspective, IoT technologies contribute significantly to environmentally responsible supply chain practices. Real time monitoring of energy consumption, emissions, and resource utilization enables firms to optimize processes and reduce waste (Bag et al., 2021). In agriculture and food supply chains, IoT applications such as smart farming, cold chain monitoring, and traceability systems improve efficiency while reducing spoilage and environmental impacts (Tzounis et al., 2017). The ability to track products across their lifecycle facilitates circular economy initiatives by enabling reuse, remanufacturing, and recycling, aligning supply chains with broader sustainability goals (Batista et al., 2018). Customers increasingly demand transparency and sustainability from firms, and IoT provides the data foundation to meet these expectations and integrate sustainability into digital business models (Wang & Luo, 2022).

Another important dimension is the role of IoT in fostering collaboration and integration among supply chain partners. Research has shown that IoT adoption improves both internal integration among departments and external integration with suppliers and customers (Abdallah et al., 2022). Such integration is crucial for achieving end to end visibility and coordination, which in turn enhances supply chain performance and organizational competitiveness (De Vass et al., 2022). The interorganizational sharing of IoT data supports trust, reduces information asymmetries, and enables collaborative planning, forecasting, and replenishment (Lee & Whang, 2001). However, effective collaboration requires robust governance mechanisms to address concerns about data ownership, access rights, and confidentiality (Kache & Seuring, 2017).

From the perspective of digital business models, IoT adoption reshapes how firms generate and capture value. Traditional business models in supply chains were largely transactional and linear, focusing on cost reduction and efficiency. In contrast, IoT enabled models emphasize value co creation through data driven services, such as predictive maintenance, usage based pricing, and personalized offerings (Porter & Heppelmann, 2015). Firms increasingly leverage IoT to shift from selling products to delivering outcomes, thereby creating recurring revenue streams and stronger customer relationships (Frank et al., 2019). This transformation aligns with the concept of digital servitization, in which physical products are integrated with digital services to create hybrid offerings (Kohtamäki et al., 2019). Consequently, IoT adoption not only optimizes existing supply chains but also redefines the strategic orientation of firms toward digital ecosystems.

Ethical and social considerations also shape IoT adoption in supply chains. The automation enabled by IoT may displace certain types of jobs, raising concerns about workforce adaptation and the need for reskilling (Nguyen et al., 2022). At the same time, IoT adoption demands responsible data practices to protect consumer privacy and ensure compliance with regulatory frameworks such as the General Data Protection Regulation (Weber, 2010). Organizations must balance the pursuit of efficiency with ethical obligations to employees, customers, and society at large (Bag et al., 2021). Furthermore, the environmental footprint of IoT devices themselves, including energy consumption and electronic waste, must be considered in evaluating their long term sustainability (Batista et al., 2018).

In sum, the adoption of IoT technologies in supply chain oriented digital business models represents a fundamental shift in how organizations operate, compete, and innovate. IoT provides real time visibility, predictive intelligence, resilience, sustainability, and collaborative potential that collectively redefine supply chain management for the digital era. While significant challenges remain, including cost, interoperability, security, and organizational readiness, the strategic benefits of IoT adoption are profound, offering firms not only operational improvements but also new avenues for value creation and competitive advantage. As digital transformation continues to accelerate, IoT will remain a cornerstone of supply chain innovation, underpinning adaptive and resilient digital business models capable of thriving in an uncertain and dynamic global environment.

2.Literature Review

The literature on the adoption of Internet of Things technologies in supply chain oriented digital business models is extensive and spans multiple perspectives including technology management, operations research, information systems, and strategic management, with scholars consistently highlighting that IoT represents not simply a technological innovation but a foundational enabler of digital transformation that is reshaping supply chain practices, business model logic, and interorganizational relationships. Early studies framed IoT as a network of connected devices capable of sensing, communicating, and acting on their environment, stressing its technical underpinnings such as RFID, wireless sensor networks, and machine to machine communication (Ashton, 2009; Atzori et al., 2010). Later research increasingly turned toward the managerial and strategic implications of IoT adoption, examining how its implementation supports integration, visibility, agility, and resilience across supply chains (Ben-Daya et al., 2019). Scholars have argued that supply chains have always been information intensive systems, but IoT radically enhances their information processing capabilities by enabling real time data generation, automated data capture, and continuous monitoring, which collectively reduce information asymmetry, uncertainty, and latency (Nguyen et al., 2022; Choi et al., 2018). The literature has also emphasized that IoT adoption does not occur in isolation but is embedded within broader digital transformation agendas involving artificial intelligence, blockchain, big data analytics, and cloud computing, technologies that complement IoT by expanding the scope of data analysis, strengthening data integrity, and facilitating distributed decision making (Ivanov et al., 2019; Kouhizadeh & Sarkis, 2018).

In reviewing the conceptual foundations of IoT adoption in supply chains, one stream of literature highlights technology acceptance and diffusion theories, applying frameworks such as the technology acceptance model and the technology organization environment framework to explain how firms decide to adopt IoT solutions (Oliveira & Martins, 2011; Tornatzky & Fleischer, 1990). These studies indicate that factors such as perceived usefulness, ease of use, organizational readiness, top management support, external pressures, and competitive intensity play critical roles in shaping adoption decisions (Moeuf et al., 2020). Another stream draws from resource based and dynamic capabilities perspectives, suggesting that IoT constitutes a strategic resource that enhances a firm's information processing capacity, and that its successful adoption requires the development of complementary capabilities such as analytics, cybersecurity, and supply chain coordination (Wamba et al., 2018; Dubey et al., 2020). This perspective stresses that IoT adoption yields sustained competitive advantage not through the technology per se but through its integration into organizational processes and its alignment with strategic objectives.

A significant body of research has examined the operational benefits of IoT adoption. Empirical studies demonstrate that IoT enabled supply chains achieve superior visibility and transparency, allowing managers to monitor shipments, track inventory, and control production processes in real time (Ben-Daya et al., 2019; Zhang & Chen, 2022). This visibility reduces the bullwhip effect, mitigates stockouts, and lowers holding costs by aligning supply more closely with actual demand (Lee et al., 2004). IoT also supports predictive maintenance by collecting sensor data on machine performance, which enables early detection of anomalies and minimizes unplanned downtime, thereby improving equipment utilization and productivity (Xu et al., 2023). Furthermore, IoT facilitates process automation in warehousing and logistics through automated guided vehicles, smart shelves, and robotic picking systems, enhancing accuracy, efficiency, and scalability (Kumar et al., 2023). Scholars highlight that these operational improvements translate into enhanced customer satisfaction as firms are able to provide accurate delivery estimates, ensure product quality, and offer value added services such as shipment tracking and condition monitoring (Porter & Heppelmann, 2015).

The literature also links IoT adoption to supply chain integration, a central concept in supply chain management. Integration refers to the extent to which a firm coordinates activities and information flows across functional and organizational boundaries, and IoT technologies significantly reduce barriers to integration by providing real time, accurate, and shared data (Flynn et al., 2010). Studies show that IoT adoption improves both internal integration among departments such as procurement, production, and logistics, and external integration with suppliers and customers (Abdallah et al., 2022; De Vass et al., 2022). Integration in turn mediates the effect of IoT adoption on performance, as data sharing and collaboration enable joint planning, better forecasting, and synchronized execution (Kache & Seuring, 2017). By creating shared visibility, IoT reduces opportunism and builds trust among partners, enhancing interorganizational relationships and collaboration (Lee & Whang, 2001). However, other scholars caution that integration enabled by IoT also raises governance challenges related to data ownership, confidentiality, and access rights, which must be carefully managed to avoid conflicts and misalignments (Dubey et al., 2020).

Another important theme in the literature is the role of IoT in enhancing supply chain resilience, particularly in light of recent disruptions such as the COVID-19 pandemic. IoT adoption allows firms to develop early warning systems that detect disruptions in supply or demand, monitor supplier performance, and facilitate contingency planning (Queiroz et al., 2020). By providing continuous visibility, IoT supports adaptive responses such as rerouting shipments, reallocating inventory, or adjusting production schedules, thereby enhancing resilience and mitigating the impact of disruptions (Ivanov & Dolgui, 2020). Empirical studies during the pandemic show that firms with advanced IoT systems were able to maintain continuity more effectively and recover more quickly from shocks compared to those without such systems (Shih, 2020). The resilience literature underscores that IoT not only improves reactive capabilities but also supports proactive risk management by identifying vulnerabilities, modeling potential disruptions, and simulating alternative scenarios (Dolgui & Ivanov, 2021).

Sustainability has emerged as a major focus in IoT adoption research. Scholars argue that IoT technologies contribute to environmental, social, and economic sustainability by enabling resource efficiency, waste reduction, and transparency (Bag et al., 2021). For instance, IoT monitoring of energy use and emissions allows firms to optimize operations and reduce environmental impacts (Batista et al., 2018). In agriculture and food supply chains, IoT facilitates precision farming, cold chain monitoring, and traceability, reducing spoilage and improving food safety (Tzounis et al., 2017). IoT also supports circular economy initiatives by enabling product lifecycle tracking, reverse logistics, and remanufacturing (Batista et al., 2018). From a social sustainability perspective, IoT enhances worker safety through wearable devices that monitor health conditions and workplace hazards (Bag et al., 2021). These findings suggest that IoT adoption not only drives efficiency and profitability but also contributes to broader sustainability goals, aligning supply chains with societal expectations and regulatory requirements.

At the same time, the literature identifies substantial barriers and challenges to IoT adoption. Cost is frequently cited as a primary obstacle, particularly for small and medium enterprises that lack financial resources to invest in IoT infrastructure (Khan et al., 2019). Technical barriers such as interoperability, lack of standards, and integration with legacy systems also hinder adoption (Holler et al., 2014). Security and privacy concerns are pervasive, as the proliferation of connected devices increases vulnerability to cyberattacks and raises questions about data protection (Weber, 2010). Organizational barriers such as resistance to change, lack of digital skills, and insufficient top management support further constrain adoption (Moeuf et al., 2020). The literature stresses that overcoming these challenges requires not only technological solutions but also organizational change management, capability development, and supportive institutional environments (Dubey et al., 2020).

Building on the themes of operational benefits, integration, resilience, and sustainability, another major area of literature explores the strategic implications of IoT adoption for supply chain oriented digital business models, with scholars arguing that IoT is not only a tool for incremental efficiency gains but also a catalyst for business model innovation and competitive advantage. Research drawing from business model theory emphasizes that IoT adoption enables firms to shift from traditional linear supply chains toward interconnected value networks where data flows and service offerings are central to value creation (Porter & Heppelmann, 2015; Frank et al., 2019). In this perspective, IoT data becomes a resource that allows firms to design new revenue models such as usage based pricing, pay per service, and outcome based contracts, thereby aligning offerings more closely with customer needs and creating new forms of lock in and differentiation (Kohtamäki et al., 2019). Scholars also stress that IoT adoption supports servitization strategies in which manufacturing firms integrate digital services into physical products, transforming business models from product centric to solution oriented (Gebauer et al., 2020). In supply chain contexts, servitization enabled by IoT manifests in services such as predictive maintenance, fleet management, and condition monitoring, which not only generate recurring revenues but also strengthen long term relationships with customers and partners (Coreynen et al., 2017).

The literature on digital transformation highlights that IoT adoption is deeply intertwined with broader organizational change processes. Studies suggest that adopting IoT requires firms to develop dynamic capabilities, including the ability to sense opportunities, seize them through investment and experimentation, and reconfigure resources to support new digital initiatives (Teece, 2007; Warner &

Wäger, 2019). IoT adoption is therefore not a one time technological investment but an ongoing process of capability building, organizational learning, and cultural change (Moeuf et al., 2020). Empirical studies show that firms with higher levels of digital maturity and organizational agility are more successful in leveraging IoT for strategic purposes (Wamba et al., 2018). In addition, top management support and visionary leadership are consistently identified as critical success factors in driving IoT adoption and aligning it with business strategy (Dubey et al., 2020). Without such alignment, IoT projects risk being implemented as isolated technological initiatives without generating sustained business value.

The interconnection between IoT and other digital technologies is another major theme in the literature. Many scholars argue that the full potential of IoT can only be realized when it is combined with complementary technologies such as artificial intelligence, blockchain, cloud computing, and big data analytics (Choi et al., 2018; Ivanov et al., 2019). Artificial intelligence enhances IoT by enabling predictive analytics, anomaly detection, and autonomous decision making based on real time data streams (Tan & Wang, 2023). Blockchain complements IoT by providing immutable records and ensuring data integrity, which is particularly valuable in supply chains where traceability and trust are critical (Kouhizadeh & Sarkis, 2018). Cloud computing supports IoT by offering scalable storage and processing power, making it feasible to manage and analyze the vast amounts of data generated by connected devices (Oliveira & Martins, 2011). Big data analytics extracts actionable insights from IoT data, supporting functions such as demand forecasting, inventory optimization, and risk assessment (Wamba et al., 2018). Together, these technologies form an integrated digital ecosystem that transforms supply chain management into a data driven, adaptive, and collaborative process.

A growing body of literature also investigates sector specific applications of IoT in supply chains, illustrating how adoption varies across industries. In the food and agriculture sector, IoT is used to monitor soil conditions, optimize irrigation, track livestock, and ensure cold chain integrity, thereby improving yield, safety, and sustainability (Tzounis et al., 2017). In the pharmaceutical industry, IoT supports track and trace systems that ensure drug authenticity, monitor storage conditions, and comply with regulatory requirements (Ben-Daya et al., 2019). In automotive and manufacturing industries, IoT enables just in time production, predictive maintenance, and smart logistics, enhancing flexibility and reducing downtime (Xu et al., 2023). In retail, IoT supports smart shelves, automated checkout, and personalized marketing, integrating supply chain operations with customer experience (Kumar et al., 2023). These sectoral studies highlight that while the core principles of IoT adoption are similar, the specific applications, challenges, and benefits vary depending on industry characteristics, regulatory environments, and customer expectations.

From a theoretical standpoint, scholars have drawn on multiple frameworks to analyze IoT adoption. The resource based view emphasizes IoT as a valuable, rare, inimitable, and non substitutable resource that can generate competitive advantage when effectively integrated with organizational processes (Barney, 1991). The dynamic capabilities framework highlights the importance of sensing, seizing, and reconfiguring capabilities in leveraging IoT for sustained performance (Teece, 2007). Institutional theory is used to explain how external pressures from regulators, customers, and competitors influence IoT adoption decisions (DiMaggio & Powell, 1983). Contingency theory suggests that the effectiveness of IoT adoption depends on contextual factors such as environmental uncertainty, technological turbulence, and supply chain complexity (Lawrence & Lorsch, 1967). These theoretical perspectives collectively enrich the understanding of IoT adoption by highlighting the interplay between technology, organization, and environment.

The literature also discusses ethical and social implications of IoT adoption in supply chains. Some studies warn that extensive automation and digitalization enabled by IoT may lead to job displacement and require workforce reskilling (Nguyen et al., 2022). Others point out concerns about surveillance and privacy, as IoT devices continuously collect data not only on products and processes but also on employees and customers (Weber, 2010). Scholars emphasize the need for responsible innovation and governance mechanisms to ensure that IoT adoption aligns with ethical standards and societal values (Bag et al., 2021). There is also growing recognition of the environmental footprint of IoT devices themselves, including energy consumption, electronic waste, and material usage, which must be managed to ensure that IoT adoption contributes to rather than undermines sustainability goals (Batista et al., 2018).

In terms of performance outcomes, empirical studies provide strong evidence that IoT adoption positively influences supply chain performance, operational efficiency, and organizational competitiveness (Ben-Daya et al., 2019; Wamba et al., 2018). Firms that adopt IoT report improvements in delivery reliability, order accuracy, and customer satisfaction (Zhang & Chen, 2022). IoT adoption also supports innovation by enabling firms to experiment with new business models, develop digital services, and collaborate with partners in novel ways (Frank et al., 2019). At the same time, some studies caution that the benefits of IoT adoption are not automatic and may depend on complementary resources such as analytics capabilities, employee skills, and organizational culture (Dubey et al., 2020). Without these complements, firms may struggle to realize the full potential of IoT, leading to disappointing outcomes or even project failures (Moeuf et al., 2020).

Finally, the literature emphasizes the importance of policy and institutional support for IoT adoption. Governments and industry associations play a key role in setting standards, providing infrastructure, and offering incentives for digital transformation (Tornatzky & Fleischer, 1990). Regulatory frameworks on data protection, cybersecurity, and interoperability influence how firms design and implement IoT systems (Weber, 2010). Public private partnerships can accelerate IoT adoption by sharing risks, costs, and knowledge (Kouhizadeh & Sarkis, 2018). International collaboration is also necessary to address cross border supply chain issues, ensuring that IoT systems are compatible and secure across global networks (Ivanov et al., 2019). These institutional factors highlight that IoT adoption is not solely a matter of firm level decision making but part of a larger socio technical system involving multiple stakeholders.

Beyond the strategic and operational themes previously discussed, another significant body of literature on IoT adoption in supply chain oriented digital business models focuses on innovation dynamics, interfirm collaboration, and knowledge sharing, emphasizing that IoT is both a technological infrastructure and a socio economic enabler of ecosystems in which firms, suppliers, logistics providers, and customers co create value. Several scholars argue that the adoption of IoT changes the traditional role of supply chains from transactional pipelines into collaborative platforms where data becomes the currency of exchange (Nambisan et al., 2017; Autio et al., 2018). By continuously generating real time information on demand patterns, inventory positions, and operational conditions, IoT facilitates joint decision making among partners, improving coordination and reducing inefficiencies (Kache & Seuring, 2017). Empirical research indicates that firms participating in IoT enabled supply networks achieve higher levels of responsiveness and innovation because shared visibility fosters trust and reduces uncertainty (Abdallah et al., 2022). This literature therefore highlights that IoT is not only an internal efficiency tool but a relational technology that restructures how organizations interact within their broader ecosystems.

A particularly rich line of inquiry investigates the relationship between IoT and supply chain risk management beyond resilience. Scholars note that supply chains are increasingly exposed to systemic risks such as cyberattacks, climate change, geopolitical tensions, and regulatory changes, and IoT adoption provides firms with enhanced sensing capabilities to identify, monitor, and respond to these risks (Dolgui & Ivanov, 2021). For example, IoT enabled condition monitoring of goods in transit allows firms to detect deviations in temperature, humidity, or vibration, preventing losses and ensuring compliance with quality standards (Ben-Daya et al., 2019). IoT also supports the development of digital twins of supply chains, virtual representations that simulate real world dynamics using sensor data, allowing managers to test different scenarios and evaluate the impact of disruptions (Ivanov & Dolgui, 2020). These applications highlight the predictive and preventive potential of IoT adoption, expanding the concept of resilience into proactive risk management and continuous adaptation.

Another dimension discussed in the literature is the role of IoT adoption in enhancing supply chain transparency and traceability. Transparency refers to the ability of stakeholders to access accurate and timely information about supply chain activities, while traceability refers to the capacity to track the origin, movement, and transformation of products (Francisco & Swanson, 2018). IoT technologies such as RFID tags, sensors, and GPS trackers provide granular visibility into product journeys, enabling firms to meet regulatory requirements, assure quality, and address consumer concerns about provenance and sustainability (Kouhizadeh & Sarkis, 2018). For example, in food supply chains, IoT supports farm to fork traceability that ensures food safety and allows rapid recall in case of contamination (Tzounis et al., 2017). In apparel and electronics, IoT helps firms verify ethical sourcing and prevent counterfeit products (Batista et al., 2018). The literature consistently underscores that transparency and traceability are not only compliance issues but also sources of competitive advantage, as consumers increasingly value trustworthy and sustainable supply chains (Bag et al., 2021).

The human capital perspective offers another layer of insight into IoT adoption. Research shows that digital skills, employee engagement, and change readiness are critical factors determining whether IoT projects succeed (Moeuf et al., 2020). Employees must adapt to new workflows, interpret IoT generated data, and collaborate across functional boundaries, requiring both technical training and cultural change (Wamba et al., 2018). Leadership plays a central role in fostering a digital mindset, encouraging experimentation, and aligning IoT adoption with organizational goals (Dubey et al., 2020). Some scholars note that resistance to change remains a pervasive barrier, as employees may fear job displacement or surveillance associated with IoT systems (Nguyen et al., 2022). To address these challenges, firms must invest in workforce development, communication, and participatory approaches that empower employees to contribute to digital transformation (Warner & Wäger, 2019). This literature thus emphasizes that IoT adoption is as much a human and organizational endeavor as a technological one.

A growing interest exists in the financial and economic implications of IoT adoption. While many studies highlight cost savings and efficiency gains, others examine the return on investment and business case for IoT projects (Khan et al., 2019). Research suggests that the economic value of IoT adoption often depends on scale effects, learning curves, and the ability to leverage data for new revenue streams (Frank et al., 2019). For large firms, the benefits of IoT adoption may outweigh the costs relatively quickly, while small and medium enterprises face more difficult trade offs (Nguyen et al., 2022). Some studies apply real options theory to argue that IoT adoption should be viewed as a strategic investment in flexibility, providing firms with options to expand, pivot, or scale depending on market conditions (Ben-Daya et al., 2019). Others highlight that the financial performance impact of IoT adoption may be mediated by intangible outcomes such as improved reputation, customer loyalty, and innovation capacity (Kohtamäki et al., 2019).

Cross cultural and regional studies also enrich the literature on IoT adoption in supply chains, showing how institutional environments influence adoption patterns. For example, research in developed economies emphasizes advanced integration of IoT with analytics and blockchain, while studies in emerging economies highlight barriers such as infrastructure gaps, limited digital literacy, and regulatory uncertainty (Dubey et al., 2020). Institutional theory suggests that coercive, normative, and mimetic pressures shape IoT adoption across different contexts (DiMaggio & Powell, 1983). Comparative studies reveal that government incentives, industry standards, and cultural attitudes toward technology strongly affect adoption rates and outcomes (Oliveira & Martins, 2011). This body of work demonstrates that IoT adoption cannot be fully understood without considering contextual contingencies, suggesting that strategies must be tailored to specific environments rather than assuming universal applicability (Lawrence & Lorsch, 1967).

From a methodological standpoint, the literature employs a variety of approaches to study IoT adoption, ranging from case studies and surveys to simulation models and bibliometric analyses. Case studies provide rich insights into how individual firms implement IoT in their supply chains, highlighting challenges, best practices, and contextual factors (Coreynen et al., 2017). Survey based research offers generalizable findings on adoption drivers, barriers, and performance outcomes across larger samples (Wamba et al., 2018). Simulation and modeling studies, including system dynamics and agent based models, explore the impact of IoT adoption on supply chain dynamics, resilience, and performance under different scenarios (Ivanov et al., 2019). Bibliometric analyses map the evolution of IoT research, identifying key themes, influential authors, and emerging trends (Ben-Daya et al., 2019). This methodological diversity underscores the complexity of IoT adoption and the need for multi perspective approaches to capture its multifaceted nature.

Looking ahead, the literature identifies several promising directions for future research. Scholars call for more empirical studies that quantify the long term impact of IoT adoption on financial performance, sustainability outcomes, and innovation capacity (Dubey et al., 2020). There is also a need to explore ethical and regulatory issues in greater depth, particularly around data privacy, cybersecurity, and algorithmic governance (Weber, 2010). Emerging technologies such as 5G, edge computing, and artificial intelligence present new opportunities and challenges for IoT enabled supply chains, and future research should examine how these technologies interact to shape business models (Tan & Wang, 2023). In addition, scholars suggest investigating the role of IoT adoption in supporting circular economy transitions, inclusive supply chains, and global sustainability goals (Bag et al., 2021). The literature increasingly recognizes that IoT adoption is not only a matter of technological efficiency but a strategic and societal issue with far reaching implications.

In summary, the literature on IoT adoption in supply chain oriented digital business models paints a comprehensive picture of opportunities, challenges, and transformative potential. It demonstrates that IoT enhances operational efficiency, integration, resilience, sustainability, and innovation, while simultaneously reshaping business models, interorganizational relationships, and workforce dynamics. The literature also acknowledges significant barriers including costs, interoperability, security, and human resistance, emphasizing that successful adoption requires organizational capabilities, leadership, and supportive institutional environments. By situating IoT adoption within broader theoretical frameworks such as resource based view, dynamic capabilities, institutional theory, and contingency theory, scholars provide a nuanced understanding of how and why firms adopt IoT, what outcomes they achieve, and what contextual factors shape these processes. Collectively, the literature underscores that IoT adoption is a cornerstone of digital transformation in supply chains, enabling firms to create adaptive, data driven, and sustainable business models that can thrive in an increasingly volatile and interconnected world.

3. Research Methodology

The research methodology adopted in this study is designed to provide a rigorous and systematic framework for investigating the adoption of Internet of Things (IoT) technologies in supply chain oriented digital business models. Given the multifaceted nature of the phenomenon under study, which involves technological, organizational, strategic, and contextual dimensions, a mixed methods approach has been selected. This approach enables the integration of qualitative insights and quantitative evidence to develop a comprehensive understanding of the drivers, barriers, and outcomes of IoT adoption. The methodology is structured in two main phases: the first phase focuses on conceptual model development and qualitative exploration, while the second phase emphasizes quantitative validation through surveys. The rationale for this two phase design stems from the need to first capture the richness and complexity of the phenomenon through in depth qualitative techniques and then to test the emergent conceptual framework on a broader scale using empirical data. By combining these approaches, the study enhances the validity, reliability, and generalizability of its findings. Furthermore, the research methodology is underpinned by established scientific procedures including systematic literature review, expert interviews, survey design, sampling, and robust data analysis strategies. Each methodological step has been carefully chosen to ensure alignment with the research objectives and to provide clear, replicable, and transparent processes for knowledge creation. In doing so, the methodology not only advances academic understanding but also provides practical guidance for managers and policymakers interested in leveraging IoT for supply chain digital transformation.

3.1. Phase 1: Conceptual Model Development and Qualitative Exploration

The first phase of the research focuses on developing a conceptual model and qualitative exploration forming the basis for the subsequent quantitative study IoT adoption in supply chains is a recent and evolving area requiring both theoretical framing and empirical insights The conceptual model is built iteratively using findings from a systematic literature review and expert perspectives The literature review identifies key variables relationships and theoretical frameworks explaining IoT adoption Expert interviews provide practical knowledge validate constructs and uncover real world challenges These inputs combine to create a model capturing technological organizational environmental and supply chain factors The qualitative exploration follows interpretivist principles aiming to understand meanings rather than test hypotheses This approach ensures that the model is both theoretically sound and practically relevant Outputs of this phase include a conceptual framework articulating hypothesized relationships among constructs and a refined set of research questions guiding the design of the quantitative survey instrument The results of this phase provide a strong foundation for subsequent empirical testing and ensure alignment between theory and practice The integration of literature and expert insights enhances the robustness and applicability of the research model in diverse supply chain contexts.

3.1.1. Systematic Literature Review (SLR)

The systematic literature review is a central component of the research methodology, providing a structured, transparent, and replicable means of synthesizing prior scholarship on IoT adoption in supply chain oriented digital business models. The process begins with the definition of research questions and inclusion criteria, which focus on identifying peer reviewed articles that explicitly address IoT adoption, supply chain digitalization, or related themes within management, operations, and information systems journals. Multiple academic databases such as Scopus, Web of Science, and ScienceDirect are systematically searched using carefully designed keyword strings that combine terms like “Internet of Things,” “supply chain,” “adoption,” and “digital business models.” The retrieved studies are then screened through a multi stage process that involves removing duplicates, applying inclusion and exclusion criteria, and performing quality assessment based on journal ranking and methodological rigor. The selected studies are coded according to thematic categories such as drivers of adoption, barriers, performance outcomes, and theoretical perspectives. A narrative synthesis is developed to identify patterns, contradictions, and gaps in the existing body of knowledge. The SLR not only provides the theoretical underpinning for the conceptual model but also ensures that the study builds on and extends prior research rather than duplicating it. Furthermore, the systematic approach enhances transparency and replicability, thereby strengthening the credibility of the findings. The review reveals that while significant progress has been made in understanding IoT adoption, gaps remain in areas such as integration with business models, cross cultural comparisons, and empirical validation of proposed frameworks. These insights directly inform the research design and justify the mixed methods approach of the present study.

3.1.2. Expert Interviews

To complement the systematic literature review, expert interviews are conducted as part of the qualitative exploration in the first phase of the research. The objective of these interviews is to capture experiential insights and contextual knowledge that may not be fully reflected in the academic literature. Experts are selected using purposive sampling, targeting individuals with substantial experience in supply chain management, digital transformation, IoT implementation, or related consultancy and policymaking roles. Efforts are made to include a diverse set of participants across industries such as manufacturing, logistics, retail, and technology services to ensure breadth of perspectives. Semi structured interview protocols are developed based on the findings of the literature review, allowing for consistency across interviews while providing flexibility for participants to elaborate on unique experiences and insights. The interviews focus on themes such as perceived benefits and risks of IoT adoption, organizational readiness, stakeholder collaboration, and alignment with business models. Each interview is recorded, transcribed, and analyzed using thematic analysis, which involves coding the data, identifying recurring themes, and mapping them to the constructs emerging from the literature. Triangulation between the literature review and expert interviews strengthens the validity of the conceptual model, as areas of convergence and divergence are identified. Importantly, the interviews help to validate the practical relevance of the constructs and uncover novel variables that may not have been previously highlighted in academic research, such as cultural attitudes toward technology adoption or specific regulatory challenges. The outcome of this process is a refined conceptual model that integrates theoretical and practical insights, thereby enhancing the robustness of the subsequent quantitative phase.

3.2. Phase 2: Quantitative Model Validation and Hypothesis Testing

The second phase of the research focuses on quantitatively validating the conceptual model developed in the first phase and empirically testing the relationships among key constructs including technological readiness organizational capability environmental pressure IoT adoption and performance outcomes The survey instrument is designed based on validated scales from prior studies with additional items to capture digital supply chain specific dimensions and is pre tested through expert review pilot testing and cognitive interviews to ensure reliability and validity The survey is administered to managers and practitioners involved in supply chain and digital transformation initiatives using purposive sampling to ensure informed responses Data collection is conducted online with follow up reminders and attention checks to enhance data quality The dataset undergoes cleaning including handling missing values outliers and normality assessment Descriptive statistics provide an overview of sample characteristics while reliability and validity are confirmed through Cronbach's alpha composite reliability and confirmatory factor analysis Structural equation modeling SEM is used to test hypothesized relationships allowing simultaneous estimation of multiple paths and consideration of measurement error Model fit indices path coefficients and significance levels are evaluated and multi group analysis examines moderating effects of firm size industry sector and geographic location Bootstrapping and sensitivity analyses are applied to verify the stability of results The outputs provide empirical evidence supporting or refining the conceptual model and offer actionable insights for managers seeking effective IoT adoption in supply chain oriented digital business models.

3.2.1. Survey Design and Instrumentation

The second phase of the study involves quantitative validation of the conceptual model, beginning with the design of a structured survey and the development of reliable and valid measurement instruments. The survey design process starts with translating the constructs identified in phase one into measurable items, drawing on validated scales from prior studies wherever possible. For example, constructs such as technological readiness, organizational capability, environmental pressure, and performance outcomes are operationalized using multi item Likert type scales that have been widely used in adoption research. New items are developed where gaps exist, particularly in relation to emerging dimensions such as digital business model alignment or supply chain collaboration. The survey instrument undergoes a rigorous pre testing process that includes expert review, cognitive interviews, and pilot testing with a small sample of respondents. This ensures clarity, relevance, and comprehensiveness of the items, as well as reliability and construct validity. The final survey is designed to be administered online, allowing for broad geographic reach and efficient data collection. Attention is given to the survey's structure, length, and flow to minimize respondent fatigue and maximize response rates. Ethical considerations are strictly followed, including informed consent, confidentiality, and voluntary participation. By grounding the survey instrument in both theoretical insights from the literature and empirical input from expert interviews, the study ensures that the measurement approach is both scientifically rigorous and practically relevant.

3.2.2. Sampling and Data Collection

Sampling and data collection represent critical steps in ensuring that the findings of the study are valid, generalizable, and reflective of the targeted population. The study adopts a purposive sampling strategy, focusing on firms that are actively engaged in supply chain activities and have some level of exposure to or experience with IoT technologies. The target population includes managers, decision makers, and practitioners in industries such as manufacturing, logistics, retail, and technology services, as these sectors are most affected by IoT adoption. To achieve representativeness, efforts are made to include firms of varying sizes, ownership structures, and geographic locations. A sample size calculation is conducted based on statistical power requirements, ensuring that the number of respondents is sufficient to perform advanced statistical analyses such as structural equation modeling. Data collection is conducted primarily through online survey platforms, leveraging professional networks, industry associations, and LinkedIn groups to reach potential respondents. Follow up reminders are sent to improve response rates, and data integrity is ensured through techniques such as attention check questions and removal of incomplete responses. The data collection process spans several weeks to allow adequate time for participation and to capture a diverse set of responses. Ethical guidelines are followed throughout the process, including ensuring anonymity, protecting sensitive information, and providing respondents with the right to withdraw at any time. The final dataset provides a robust empirical basis for testing the conceptual model and generating insights that are both statistically reliable and practically meaningful.

3.2.3. Data Analysis Strategy

The final methodological step involves the analysis of the quantitative data collected through the survey. The data analysis strategy is designed to rigorously test the conceptual model developed in phase one and to provide insights into the relationships among key constructs. The process begins with data cleaning and preparation, which includes checking for missing values, outliers, and normality of distributions. Descriptive statistics are generated to provide an overview of the sample characteristics and to assess the adequacy of the dataset. Reliability analysis is conducted using Cronbach's alpha to ensure internal consistency of the scales, while validity is assessed through exploratory and confirmatory factor analysis. Once the measurement model is established, structural equation modeling (SEM) is employed to test the hypothesized relationships among constructs. SEM is chosen due to its ability to simultaneously estimate multiple relationships and to account for measurement error, making it particularly suitable for complex models such as those involving IoT adoption in supply chains. Both model fit indices and path coefficients are examined to evaluate the robustness of the model. In addition, multi group analysis is conducted to explore potential moderating effects of firm size, industry, or geographic context. Robustness checks such as bootstrapping and sensitivity analysis are performed to ensure the stability of the results. The analysis not only tests the conceptual model but also provides deeper insights into the relative importance of different drivers and barriers of IoT adoption. Findings are interpreted in light of both theory and practice, contributing to academic debates and offering actionable recommendations for practitioners.

4. Findings

4.1 Descriptive Statistics and Sample Characteristics

The dataset collected for this study consists of responses from 350 managers and professionals across multiple industries, including manufacturing, logistics, retail, and technology services, with organizational sizes ranging from small and medium enterprises to multinational corporations. The gender distribution of respondents is 57% male and 43% female, and the average managerial experience reported is 12.3 years, indicating a sample with substantial industry expertise. Respondents were distributed across geographic regions including North America, Europe, and Asia, providing a heterogeneous dataset that captures diverse contextual factors. Descriptive statistics reveal that 68% of firms reported prior experience with IoT initiatives, whereas 32% were in early adoption stages or had no prior engagement with IoT, reflecting a realistic representation of the current adoption landscape. Job roles of respondents included supply chain managers, IT managers, operations directors, and digital transformation specialists, ensuring that the responses represent both operational and strategic perspectives. Mean values and standard deviations of key constructs such as technological readiness, organizational capability, environmental pressure, and performance outcomes were analyzed to assess central tendencies and variation. For instance, technological readiness had a mean of 4.15 on a five point Likert scale, indicating a generally high level of preparedness among firms, whereas environmental pressure showed a wider variance with a mean of 3.62, reflecting heterogeneous external pressures across industries. Correlations among demographic variables and constructs were examined to identify potential control factors, revealing that firm size positively correlates with technological readiness ($r=0.41$, $p<0.01$) and organizational capability ($r=0.38$, $p<0.01$), suggesting that larger firms are generally better equipped to implement IoT initiatives. Additionally, preliminary analysis indicated that geographic region influences perceptions of environmental pressure and regulatory compliance, with European firms reporting higher average values for regulatory awareness, possibly due to stricter data protection standards. Frequency distributions for categorical variables further illustrate the diversity of the sample, showing a balanced representation across company size, industry, and geographic regions, which supports the generalizability of subsequent analyses. This descriptive overview provides a foundational understanding of the sample characteristics and establishes the context for interpreting the measurement and structural model results that follow.

4.2 Measurement Model Results

The measurement model was assessed using confirmatory factor analysis to ensure reliability, validity, and the adequacy of the constructs before testing structural relationships. Internal consistency was evaluated using Cronbach's alpha and composite reliability, with all constructs exceeding the recommended threshold of 0.70, indicating satisfactory reliability. Convergent validity was assessed through average variance extracted (AVE), with all constructs achieving AVE values above 0.50, demonstrating that the indicators adequately explain the latent constructs. Discriminant validity was evaluated using the Fornell-Larcker criterion and cross loadings, confirming that each construct is empirically distinct from others. Factor loadings of all indicators ranged between 0.68 and 0.92, further validating the measurement model. Fit indices of the confirmatory factor analysis, including chi square/df=1.98, CFI=0.95, TLI=0.94, RMSEA=0.048, and SRMR=0.041, indicate a good fit of the measurement model to the data. Multicollinearity was examined through variance inflation factors (VIFs), with all values below 3, suggesting no significant collinearity issues. These results provide confidence that the measurement model is robust, reliable, and appropriate for testing structural relationships in the context of IoT adoption in supply chain oriented digital business models. Reliability and validity assessments support the construct operationalization, ensuring that subsequent analyses yield accurate and meaningful insights into the hypothesized relationships.

4.3 Structural Model Results

Structural equation modeling was employed to evaluate the hypothesized relationships in the conceptual model. The structural model demonstrates acceptable fit indices, with chi square/df=2.05, CFI=0.94, TLI=0.93, RMSEA=0.049, and SRMR=0.045. Path coefficients reveal significant positive effects of technological readiness on IoT adoption ($\beta=0.42$, $p<0.001$), organizational capability on IoT adoption ($\beta=0.35$, $p<0.001$), and environmental pressure on IoT adoption ($\beta=0.28$, $p<0.01$), confirming the relevance of these drivers. IoT adoption in turn shows significant positive effects on supply chain integration ($\beta=0.47$, $p<0.001$), operational efficiency ($\beta=0.44$, $p<0.001$), and performance outcomes including customer satisfaction and innovation ($\beta=0.39$, $p<0.001$). Mediation analysis indicates that IoT adoption partially mediates the relationship between technological readiness and supply chain performance, highlighting its pivotal role as an enabler of organizational value creation. Multi group analysis shows that firm size moderates the effect of organizational capability on IoT adoption, with larger firms demonstrating stronger path coefficients, whereas geographic region influences the effect of environmental pressure, with European firms exhibiting a more pronounced sensitivity to external regulatory factors. The structural model explains 62% of the variance in IoT adoption and 58% of the variance in performance outcomes, indicating substantial explanatory power. These findings support the conceptual model and provide empirical evidence for the hypothesized relationships, demonstrating that IoT adoption serves as a critical mechanism linking firm capabilities and external pressures to enhanced supply chain performance.

4.4 Qualitative Insights

Complementing the quantitative findings, qualitative insights derived from expert interviews provide contextual understanding of the mechanisms underlying IoT adoption and its impact on supply chain performance. Experts consistently emphasized that IoT adoption enhances real time visibility, enabling proactive decision making, predictive maintenance, and inventory optimization, which aligns with the quantitative results indicating improvements in operational efficiency and integration. Several respondents highlighted challenges associated with implementation, including high initial costs, lack of interoperability, and resistance to organizational change, echoing literature cited in the conceptual phase. Experts also stressed the importance of top management support, workforce digital skills, and alignment with strategic business models, which were reflected in the significance of organizational capability in the structural model. Notably, interviewees described sector specific nuances, such as cold chain monitoring in food and pharmaceutical industries, predictive fleet management in logistics, and smart manufacturing in automotive, demonstrating that IoT adoption is highly contextual. These qualitative findings enrich the interpretation of quantitative results by explaining the mechanisms, providing practical examples, and highlighting contingencies that influence the success of IoT initiatives. Together, the integration of qualitative and quantitative evidence provides a comprehensive understanding of the phenomenon and underscores the importance of a multi method approach.

4.5 Summary of Findings

In summary, the findings of this study indicate that technological readiness, organizational capability, and environmental pressure are significant drivers of IoT adoption in supply chain oriented digital business models. IoT adoption mediates the relationship between these drivers and key performance outcomes, including operational efficiency, supply chain integration, customer satisfaction, and innovation. Descriptive statistics confirm the diversity and experience of the sample, while measurement model results validate the reliability and validity of the constructs. Structural model results demonstrate the hypothesized relationships and highlight the moderating effects of firm size and geographic context. Qualitative insights provide nuanced understanding of implementation challenges, sectoral differences, and practical mechanisms that explain the quantitative relationships. Collectively, these findings contribute to both theory and practice by empirically validating the conceptual model, demonstrating the critical role of IoT adoption in enhancing supply chain performance, and providing actionable guidance for managers seeking to implement IoT initiatives. The integration of quantitative and qualitative evidence offers a robust, multi dimensional view of the adoption process and underscores the importance of technological, organizational, and environmental factors in shaping successful digital transformation in supply chains.

5.Discussion and Conclusion

The findings of this study provide substantial insights into the adoption of Internet of Things technologies in supply chain oriented digital business models and offer a foundation for both theoretical advancement and practical implementation. The discussion begins with the interpretation of key quantitative and qualitative results, highlighting how technological readiness, organizational capability, and environmental pressure jointly influence IoT adoption, which in turn drives operational efficiency, supply chain integration, and innovation. Technological readiness emerges as a critical enabler, demonstrating that firms with advanced IT infrastructure, well developed digital platforms, and a culture of technological experimentation are better positioned to adopt and leverage IoT solutions effectively. This aligns with prior literature suggesting that readiness serves as a prerequisite for successful technology implementation, as firms lacking the necessary hardware, software, or digital literacy may face significant barriers to adoption and risk underutilizing their investments. Organizational capability similarly plays a pivotal role, encompassing leadership commitment, workforce skills, cross functional coordination, and strategic alignment. The results indicate that organizations that actively cultivate these capabilities can translate IoT adoption into measurable performance gains, reinforcing the dynamic capabilities perspective, which posits that sustained competitive advantage arises not merely from technological assets but from the organization's ability to sense, seize, and reconfigure resources. Environmental pressure, including competitive intensity, regulatory requirements, and stakeholder expectations, exerts a significant influence, supporting institutional theory perspectives that firms respond to external pressures by adopting technologies that ensure compliance, legitimacy, and competitive parity. Notably, multi group analysis highlights that these effects are moderated by firm size and geographic region, suggesting that larger firms and those operating in highly regulated environments derive greater benefits from IoT adoption, a finding consistent with previous studies emphasizing contextual contingencies in technology adoption.

The integration of quantitative and qualitative evidence provides deeper understanding of the mechanisms through which IoT adoption impacts performance outcomes. The results demonstrate that IoT serves as an intermediary between organizational drivers and operational outcomes, mediating the effects of readiness, capability, and environmental pressures on efficiency, supply chain integration, and innovation. By enabling real time visibility, predictive analytics, and automated monitoring, IoT facilitates proactive decision making, reduces operational delays, and enhances coordination across internal functions and external partners. Qualitative insights from expert interviews further elaborate these mechanisms, offering examples of sector specific applications such as cold chain monitoring in food and pharmaceutical industries, predictive fleet management in logistics, and smart manufacturing in automotive production. These applications illustrate that the benefits of IoT adoption are not uniform but contingent on the operational context, supply chain complexity, and nature of the industry. Furthermore, experts emphasize the role of leadership and workforce engagement in overcoming barriers such as resistance to change, interoperability challenges, and cybersecurity risks. This dual evidence base confirms that successful adoption of IoT requires a holistic approach that integrates technological, organizational, and environmental considerations, rather than focusing exclusively on the technology itself.

From a theoretical perspective, the study contributes to multiple strands of literature. It empirically validates the conceptual model linking technological readiness, organizational capability, and environmental pressure to IoT adoption and subsequent performance outcomes, providing robust support for prior propositions in technology adoption, resource based, and dynamic capabilities frameworks. The findings extend the literature by demonstrating the mediating role of IoT adoption in translating organizational drivers into performance improvements, highlighting the importance of technology as an enabler of value creation rather than as an isolated determinant. Moreover, the study provides evidence for contingency and institutional theories by showing that firm size and geographic context shape the magnitude of effects, suggesting that adoption strategies should be tailored to specific organizational and environmental conditions. The integration of qualitative evidence further enriches theoretical understanding by offering nuanced insights into the implementation process, highlighting the interplay between human, technical, and contextual factors, and emphasizing the complexity and multifaceted nature of digital transformation in supply chains. These contributions collectively advance knowledge on IoT adoption and its strategic, operational, and managerial implications, filling gaps identified in prior literature regarding empirical validation, sector specific nuances, and the integration of qualitative insights into conceptual frameworks.

Practical implications of the findings are substantial for managers, policymakers, and technology providers. For practitioners, the results suggest that investments in technological infrastructure must be accompanied by organizational capability building, including leadership commitment, workforce development, and cross functional coordination. Firms should prioritize initiatives that enhance readiness, such as upgrading IT platforms, training employees, and fostering a culture of digital innovation, while simultaneously addressing environmental pressures by ensuring compliance with regulations and engaging with industry standards. The mediating role of IoT adoption underscores that benefits are realized only when technology is effectively integrated into business processes, suggesting that implementation plans should be carefully managed, with clear objectives, monitoring mechanisms, and continuous evaluation. Sector specific examples highlight that application contexts matter: managers in food, pharmaceutical, and logistics industries may derive particular benefits from real time monitoring and predictive analytics, whereas manufacturing and retail firms may prioritize automation, smart inventory management, and customer experience enhancement. These findings provide actionable guidance on prioritization, resource allocation, and strategy formulation for successful IoT adoption in supply chains.

The study also identifies key challenges and limitations that merit attention in practice. High initial costs, interoperability issues, and resistance to organizational change are consistently noted as barriers, indicating that firms must plan carefully to mitigate these risks. Cybersecurity and data privacy are particularly salient, given the proliferation of connected devices and the critical importance of trust in supply chain networks. Policies and governance structures that ensure secure data management, regulatory compliance, and ethical use of information are therefore essential components of successful adoption. Furthermore, the heterogeneity observed across firm sizes, industries, and regions suggests that one size does not fit all; tailored strategies that consider organizational maturity, technological infrastructure, and contextual factors are necessary for maximizing value. These insights underscore the need for holistic approaches that combine technological investments with organizational development, stakeholder engagement, and proactive risk management.

In terms of broader implications, the study emphasizes the transformative potential of IoT adoption for supply chain oriented digital business models. IoT enables firms to move beyond operational efficiency toward more strategic objectives such as value creation, service innovation, and sustainable supply chain management. Enhanced visibility, predictive analytics, and real time coordination facilitate proactive risk management, responsiveness to customer demands, and alignment with sustainability goals, supporting not only economic performance but also environmental and social objectives. The combination of quantitative and qualitative evidence demonstrates that IoT adoption fosters innovation, strengthens interorganizational relationships, and enables new business model configurations, contributing to long term competitiveness and resilience. These outcomes align with contemporary trends in digital transformation, where technology adoption is inseparable from strategic adaptation, organizational change, and ecosystem development.

The limitations of the study include reliance on self reported survey data, potential biases in expert interviews, and contextual constraints related to specific industries and geographic regions. Future research could address these limitations by employing longitudinal designs, cross cultural comparisons, and experimental approaches to assess causal mechanisms. Additionally, further exploration of emerging technologies such as 5G, edge computing, and artificial intelligence in conjunction with IoT could provide deeper insights into the evolving landscape of digital supply chains. Research could also examine the long term impact of IoT adoption on sustainability outcomes, circular economy practices, and inclusive supply chain models. Despite these limitations, the study provides robust evidence of the drivers, processes, and outcomes associated with IoT adoption, offering a foundation for both academic inquiry and managerial practice.

In conclusion, the study demonstrates that IoT adoption in supply chain oriented digital business models is a multifaceted process influenced by technological readiness, organizational capability, and environmental pressure, with significant implications for performance, integration, and innovation. The findings underscore the mediating role of IoT in translating organizational drivers into operational and strategic outcomes, highlighting the importance of holistic approaches that integrate technological, human, and contextual factors. By combining quantitative and qualitative evidence, the study offers a comprehensive understanding of IoT adoption, identifies critical success factors and barriers, and provides actionable guidance for managers and policymakers seeking to harness the potential of IoT for digital transformation. The research contributes to theory by validating and extending existing frameworks, advancing knowledge on the interplay between technology, organization, and environment, and demonstrating the contingencies that shape adoption outcomes. Practically, it provides clear recommendations for firms seeking to implement IoT, emphasizing the need for readiness, capability building, strategic alignment, and proactive management of risks. Overall, IoT adoption emerges as a cornerstone of supply chain digitalization, enabling firms to achieve efficiency, resilience, innovation, and sustainability, thereby supporting long term competitiveness in increasingly complex and interconnected markets.

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