Framework for IoT Technology Adoption in Third-Party Logistics:

Evaluation at FedEx Europe

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Framework for IoT Technology Adoption in Third-Party Logistics: Evaluation at FedEx Europe

by

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Preface

It is bittersweet to think that writing this page marks the end of a journey filled with discovery, resilience, and transformation. As I write, I'm drawn to reflect on the moments that led me here, from initial sparks of curiosity to the countless hours of research that shaped this work. Choosing to delve into the complexities of technology adoption wasn't just about following a professional path; it was a leap into the unknown, driven by a vision of what could be achieved with IoT in this field. With each step, what began as an exploration evolved into a mission – to bridge the gap between cutting-edge innovation and practical solutions that can reshape an industry. This work was far from a solitary endeavor. The insights I've gathered and the framework I developed stand on the shoulders of those who believed in this project and offered their guidance, wisdom, and encouragement. Reaching this moment has been an extraordinary process of learning, and my hope is that the impact of this work resonates beyond these pages, inspiring future research and practical change within this dynamic field.

First, I extend my deepest gratitude to my academic supervisors, Marcel Ludema and Marcela Tuler de Oliveira, my committee chair, Jolien Ubacht, as well as my company supervisors, Vasile Catalin Turta and Georgiana Constantin. Each of you has contributed uniquely to both my professional and personal growth. Marcel, from the start, you promised to push me, as a researcher and engineer, to become my best for this project, and you kept your word. You challenged me at every step to think broadly, consider all paths, and strive for the best choices. Your passion for this topic shone through, and I truly value our lengthy discussions, even if I borrowed more of your time than intended. Marcela, your unwavering faith in this research, even when the pieces were just beginning to form, has guided me throughout. Thank you for your excitement, support, clear guidance, and the laughs that came with it. Jolien, your patience and ability to see the bright side is truly inspiring. Your constructive feedback kept things in perspective, especially during challenging moments. Catalin and Georgiana, you grounded me in the industry's reality and ensured this innovation tool came to life. Your practical insights have been invaluable, and I hope this work brings you as much satisfaction as it has brought me. This has been a wonderful team effort, characterized by equal parts hard work, excitement, and laughter.

I am also grateful to FedEx and their European Planning and Engineering department for supporting me and providing the collaborative environment that brought this project to life. To my colleagues who took part in the interviews, thank you for your openness and for sharing your experiences, perspectives, and challenges in adopting IoT within logistics. Your insights form the very core of this framework, and without them, this research would have been incomplete. Beyond work, you offered support, laughter, and camaraderie, making this experience all the richer.

To my family and friends – your steadfast encouragement and patience have carried me through the most challenging moments of this journey. To my parents and sister, in particular, who suffered my neglect in all matters unrelated to this topic during the peak months of this research, thank you for being understanding, patient, and incredibly supportive even from a distance. Thank you for your unwavering belief in me, for lifting me up when I doubted myself, and for reminding me why I started this journey in the first place. To my friends, who contributed to the crucial moments of reprieve and comic relief during this time, thank you for sticking with me through the highs and lows. Your companionship and positive outlook in navigating these uncertain waters have been invaluable, reminding me that, in this shared experience, there is strength and resilience.

If there's one thought that perfectly sums up this research journey, it is that transformation lies at the heart of the people who push it forward. We, engineers, unlike our technological innovations, are human, and sometimes we make mistakes. Failure is not bad, nor is it the end, but rather an opportunity to improve in the future. As IoT reshapes the industry, I am filled with gratitude and optimism to have contributed to this ever-evolving field. Here's to the innovations that drive us and to the people who make them possible.

Andreea Bitirez
Delft, November 2024

Summary

The future of logistics is smart, connected, and driven by data. The rapid advancements in IoT technology hold significant promise for reshaping logistics operations. The ultimate goal is to achieve smart warehousing, where IoT-driven systems autonomously track assets, optimize workflows, and predict maintenance needs in real-time, unlocking unprecedented levels of efficiency and responsiveness. IoT technologies have the potential to transform how logistics companies manage their operations by enhancing visibility, reducing downtime, and improving decision-making through data-driven insights. These capabilities not only promise to streamline supply chain processes but also to improve customer satisfaction by providing faster and more accurate delivery services. One of the key benefits of IoT in logistics is its ability to provide real-time data that allows for more accurate decision-making. For instance, GPS tracking and telematics systems enable logistics providers to monitor the location and condition of their fleet at any given time, reducing the risk of delays or damage. Similarly, RFID tags and smart sensors can be used to track inventory levels, ensuring that warehouses are always stocked with the right amount of products to meet demand. Additionally, predictive maintenance systems can help avoid costly equipment failures by monitoring the condition of machinery in real-time, ensuring that repairs are made before a breakdown occurs. By using these technologies, logistics companies can optimize their operations, reduce waste, and improve overall efficiency.

However, despite the immense potential of IoT, adoption remains fraught with technical, organizational, and financial challenges that prevent many third-party logistics firms (3PLs) from fully capitalizing on these innovations. One major hurdle is the difficulty of integrating IoT solutions with legacy systems. Many 3PLs still rely on outdated technology, which may not be compatible with modern IoT solutions. This can result in significant integration challenges, requiring extensive system upgrades and costly IT investments. Another major challenge is organizational resistance to change, as employees accustomed to traditional logistics practices may be hesitant to adopt new, technology-driven processes. This resistance can hinder the effectiveness of IoT initiatives, particularly if employees are not adequately trained or if the benefits of the technology are not clearly communicated to them. Financial considerations also pose a significant barrier to IoT adoption. Implementing IoT solutions often requires a substantial upfront investment in hardware, software, and infrastructure. Additionally, ongoing costs related to system maintenance, data management, and training can strain budgets, particularly for smaller logistics providers. These financial challenges can lead to stalled projects or an inability to scale IoT solutions beyond the pilot stage, a phenomenon often referred to as "pilot purgatory." In this scenario, companies may successfully test IoT technologies on a small scale but fail to implement them company-wide due to cost constraints, unclear returns, or a lack of organizational buy-in. Despite these challenges, the potential for IoT to revolutionize logistics operations remains vast. To fully realize the benefits, 3PL companies need a structured framework to IoT adoption, one that addresses such technical, organizational, and financial challenges head-on. By doing so, logistics providers can unlock the full potential of IoT technologies, transforming their operations and gaining a competitive edge in an increasingly data-driven industry.

This study presents the IoT Technology Adoption Framework (ITAF), developed to help logistics companies overcome these challenges and successfully implement IoT solutions. The framework guides companies through each phase of IoT adoption, ensuring that they are prepared to address the unique barriers they face. By following a structured, stage-gated process, companies can make informed decisions, mitigate risks, and ultimately achieve a smooth transition to large-scale IoT implementation. The study aims to contribute to this field of research by addressing the following research question:

How can the challenges faced by third-party logistics (3PL) companies in new IoT technology adoption be addressed and mitigated by means of a structured framework?

To guide logistics companies through the complexities of IoT adoption and ensure these technologies become seamlessly integrated into their operations, this study addressed the research question in a holistic and systematic way using a Design Science Research (DSR) approach, which combines theoretical insights and practical feedback to design, evaluate, and refine the framework. As such, the design objective for this research is to develop a structured, adaptable framework that facilitates the seamless adoption of IoT technologies within third-party logistics (3PL) companies.

First, the foundation for the framework is built by reviewing existing literature on IoT adoption in the logistics sector, therefore exploring the technical, organizational, and financial challenges that 3PL companies face when trying to integrate IoT into their operations. Through the literature review, the study identifies key barriers, such as the complexity of legacy systems, resistance to change within organizations, and the high costs associated with implementing new technologies. These insights are used to develop a set of initial design requirements for the ITAF, ensuring that the framework addresses the most pressing challenges. As such, the first prototype of the IoT Technology Adoption Framework (ITAF) is introduced. It is designed to guide logistics companies through five key stages of IoT adoption: identifying challenges, assessing capabilities, planning, pilot testing, and large-scale implementation. Each stage includes decision gates, which act as checkpoints where companies can evaluate their progress and determine whether to move forward, adjust their approach, or abandon a project. The framework also includes evaluation metrics to help companies assess the technical, organizational, and financial viability of their IoT projects. The ITAF prototype is then evaluated through expert interviews with industry professionals from FedEx Europe, a leading 3PL company at the global scale. These interviews provide valuable insights into the practical challenges FedEx faces in adopting IoT technologies, particularly in integrating new solutions with existing systems and overcoming organizational resistance. Based on the expert feedback, the ITAF is revised to better address the complexities of IoT adoption in large logistics companies. A new set of requirements is introduced for vendor involvement, pilot installation, continuous reassessment of company capabilities, and the incorporation of cost-benefit analysis in the post-launch review. These refinements make the framework more adaptable and scalable, ensuring that it can be applied across a range of logistics environments, from small regional operators to large global players like FedEx.

The revised and proposed IoT Technology Adoption Framework (ITAF) provides a structured, stage-gated process tailored for third-party logistics (3PL) companies to address the complex challenges of adopting IoT. ITAF serves as a practical, step-by-step guide for engineers, managers, and other decision-makers to overcome the technical, organizational, and financial barriers that typically hinder IoT integration in logistics. Key challenges ITAF addresses include ensuring system interoperability between IoT and legacy systems, managing high upfront and ongoing costs, and reducing employee resistance to change. Each phase of ITAF includes decision gates that allow companies to evaluate their readiness to advance or adjust their approach. This structure helps to mitigate risks early, ultimately enabling logistics providers to fully leverage IoT's potential without disrupting current operations.

A major advantage of ITAF is its flexibility, allowing it to be tailored to the size and needs of a logistics provider. Small companies, for instance, can focus on the financial aspects of IoT adoption, while larger organizations may prioritize system compatibility and readiness. ITAF's modular nature also means it can be adjusted based on the specific IoT technologies being implemented, making it scalable for applications ranging from fleet management to real-time inventory tracking. The adaptability of ITAF extends beyond logistics, with applications in sectors like healthcare, manufacturing, and retail that face similar IoT integration challenges. These industries, like logistics, require careful management of large datasets and smooth integration with existing systems. Testing ITAF in diverse environments could validate its effectiveness and guide further refinements, enhancing its scalability and utility across industries.

As IoT technology advances rapidly, ITAF supports ongoing reassessment and updates, helping companies stay aligned with new technological and industry standards. This approach is critical in the evolving IoT landscape, where continuous learning and adaptation are essential to maintaining a competitive edge. Recommendations from ITAF's evaluation emphasize that logistics providers should not only focus on the initial investment but also on long-term adaptability, enabling IoT projects to evolve as new technologies emerge. By using a structured framework, companies can better manage this dynamic process, ensuring they remain at the forefront of IoT innovation. Additionally, establishing clear stakeholder ownership at each decision gate ensures accountability and minimizes delays throughout implementation. With ITAF, companies can better manage this dynamic process, ensuring they remain at the forefront of IoT innovation.

Therefore, ITAF's stage-gated, adaptable approach provides a practical roadmap for navigating IoT adoption's complexities, making it a valuable tool not only for logistics providers but also for other sectors poised to benefit from IoT's transformative potential.

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Acronyms

3PL	Third-Party Logistics
ADKAR	Awareness, Desire, Knowledge, Ability, Reinforcement Model
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AMR	Autonomous Mobile Robot
DCF	Dynamic Capabilities Framework
DSR	Design Science Research
ERP	Enterprise Resource Planning
GPS	Global Positioning System
IDT	Innovation Diffusion Theory
ITAF	IoT Technology Adoption Framework
MoSCoW	Must have, Should have, Could have, Won't have
RBV	Resource-Based View
RFID	Radio Frequency Identification
TAM	Technology Acceptance Model
TOE	Technology-Organization-Environment Framework
TRI	Technology Readiness Index
UTAUT	Unified Theory of Acceptance and Use of Technology
WMS	Warehouse Management Systems
WSN	Wireless Sensor Network
3PL	Third-Party Logistics

1 Introduction

This chapter introduces the topic of the research project, focusing on the challenges of IoT adoption in the logistics sector, and particularly within third-party logistics (3PL) providers. First, the initial problem is presented and contextualized. Following this, the research gap is identified through a summary of existing literature. The main research question is then formulated based on these insights, addressing how IoT adoption challenges can be mitigated through a structured framework. Finally, the relevance of this study to the Complex Systems Engineering and Management (CoSEM) program is demonstrated, showcasing how the research integrates both technical and socio-technical perspectives.

1.1 Background

In today's rapidly advancing technological landscape, businesses are under immense pressure to keep pace with the ever-evolving expectations of their customers. Across all sectors, the drive to remain competitive has led companies to explore and implement emerging technologies that promise greater efficiency, cost savings, and improved customer experiences. This has become particularly relevant in the logistics sector. Customers have grown to expect fast, reliable, and affordable delivery of goods at a time when online shopping and eCommerce are booming. The effect of globalization has made the world more interconnected than ever, amplifying these expectations as consumers now have access to goods and services from around the globe, further increasing the demand for efficient, cross-border logistics solutions (Shang et al., 2012; Singh & Singh, 2015). As such, the logistics sector has witnessed significant technological advancements over the past decade. Digital innovations such as the Internet of Things (IoT), robotics, blockchain, and, more recently, artificial intelligence (AI) have reshaped logistics operations and the supply chain, offering businesses new ways to streamline operations, enhance visibility, and deliver superior service (Singh & Singh, 2015; Khan et al., 2023).

Of these technologies, IoT has emerged as a key enabler of transformation within logistics, particularly in the eCommerce and retail sectors. IoT refers to the interconnection of devices embedded with sensors and software that collect and exchange data in real-time, providing unprecedented visibility into operations (Singh & Singh, 2015; Amazon, 2024). In the context of logistics, IoT allows companies to track assets, monitor environmental conditions, optimize inventory, and automate processes with real-time insights. These capabilities are crucial for enhancing operational efficiency, improving accuracy, and driving better decision-making. While the concept of IoT is not entirely new, its full potential is still being explored and unlocked as technology improves, making it a driving force in digital transformation and a critical component of emerging technologies (Shang et al., 2012).

The ultimate goal for many in the logistics industry is the development of fully automated "smart warehouses", where IoT, robotics, and other advanced technologies work together to manage inventory, sort shipments, and facilitate the flow of goods with minimal human intervention (Kamali, 2019; Zhen & Li, 2022). Smart warehouses use automated systems to streamline tasks such as picking, packing, and shipping, all while relying on real-time data to make informed adjustments and optimize workflows (Khan et al., 2023). The promise of smart warehouses lies in their ability to drastically reduce labor costs, minimize errors, and accelerate delivery times, ultimately improving customer satisfaction (Kamali, 2019; Zhen & Li, 2022).

Several eCommerce companies have already made significant strides toward realizing this vision. For instance, Amazon has implemented AWS IoT, a platform that facilitates real-time data collection and device management across its supply chain. Its Amazon Go stores, equipped with IoT sensors, have revolutionized the retail experience by enabling cashier-less shopping for easier transactions (Amazon, 2024; Greenawalt, 2024). Similarly, Alibaba's Cloud IoT platform offers real-time logistics monitoring, ensuring efficiency in its massive global operations (Alibaba Cloud IoT, 2024). JD.com has advanced IoT adoption further by incorporating IoT-connected drones for autonomous deliveries in remote regions, demonstrating the potential for IoT to not only optimize warehouse operations but also expand the reach of logistics networks (Cao, 2020).

In fact, some leading companies have already made significant strides toward achieving fully operational smart warehouses, leveraging IoT, robotics, and automation to optimize their logistical processes. Ocado, a UK-based online grocery retailer, operates some of the most advanced smart warehouses globally, relying on IoT-driven robotics to handle complex tasks with minimal human oversight (Killick, 2023). Amazon, with its vast network of semi-automated warehouses, uses IoT-enabled Kiva robots to manage inventory and streamline order fulfillment processes (Greenawalt, 2024). JD.com has implemented smart warehouses across China, integrating IoT, AI, and robotics to automate storage and delivery systems, including the use of drones for last-mile delivery (Cao, 2020). Alibaba operates IoT-powered warehouses that leverage automation to optimize inventory management and improve efficiency across its global eCommerce operations (Alibaba Cloud IoT, 2024).

These examples showcase the tremendous progress made by eCommerce companies in leveraging IoT technologies to build fully automated, efficient operations. The result has been faster delivery times, reduced labor costs, increased accuracy in inventory management, and improved customer satisfaction – factors that have given these companies a significant competitive edge (Kamali, 2019; Zhen & Li, 2022).

While eCommerce companies have been quick to adopt IoT technologies and achieve smart warehousing, third-party logistics (3PL) providers have lagged behind in this regard. Unlike eCommerce companies, which typically manage their own inventory and directly control their warehousing and distribution processes, 3PL providers offer outsourced logistics services to support other businesses' supply chains. These services can include warehousing, transportation, inventory management, order fulfillment, and even packaging and freight forwarding. Companies like DHL, UPS, FedEx, DB Schenker, and XPO Logistics are well-known examples of 3PL providers operating on a vast scale to help clients manage complex logistics operations without requiring them to invest in infrastructure and specialized logistics expertise. The role of 3PL providers is pivotal, especially for companies looking to scale efficiently without taking on the costs and complexities of in-house logistics. The disparity in IoT adoption between eCommerce and 3PL companies can be attributed to several factors that require further exploration (Zhen & Li, 2022). Although IoT offers clear benefits – such as real-time visibility, predictive maintenance, and process automation – 3PL providers face more complex operational challenges that have slowed their progress toward full IoT integration (Kamali, 2019; Cao, 2020). A fully automated 3PL smart warehouse has yet to be achieved despite advancements in fleet management and shipment tracking systems (Greenawalt, 2024).

Thus, while both eCommerce and 3PL providers have implemented IoT technologies in part, 3PL companies are visibly slower to adopt IoT on a larger scale (Zhen & Li, 2022; Cao, 2020). This lag in adoption creates a technological gap between the two industry sectors, with 3PLs struggling to keep pace with the rapid advancements seen in eCommerce. This challenge needs to be addressed with urgency, as the gap is likely to widen further with the accelerating pace of technological innovation (Shang et al., 2012).

1.2 Problem Identification

While IoT technologies have transformed the logistics operations of eCommerce giants, 3PL providers have struggled to achieve the same level of integration (Zhen & Li, 2022; Cao, 2020). Despite their crucial role in the logistics ecosystem, 3PL companies have found it difficult to implement IoT solutions at scale (Kamali, 2019). This discrepancy in IoT adoption can be attributed to a number of factors, including the complexity of 3PL operations, financial constraints, and organizational resistance to technological change (Zhen & Li, 2022).

One of the key issues that hinders IoT adoption in 3PL companies is the inherent complexity of their business models (Zhen & Li, 2022). Unlike eCommerce companies, which often have more direct control over their supply chains, 3PL providers must manage a diverse range of clients, services, and operational requirements (Kamali, 2019). The nature of 3PL operations involves handling logistics for various industries, each with its own set of challenges, from managing different types of goods to complying with a wide range of regulatory and safety requirements. This diversity complicates the integration of IoT systems, which require a high degree of customization and flexibility to accommodate the specific needs of each client (Singh & Singh, 2015; Shang et al., 2012).

In addition, the financial costs associated with implementing IoT technologies in 3PL operations are significantly higher than in eCommerce companies. Building IoT-enabled smart warehouses, deploying sensors across a global fleet of vehicles, and integrating IoT solutions into existing legacy systems all require substantial upfront investment (Singh & Singh, 2015). This is largely due to the dynamic nature and high variety of services required. 3PL warehouses manage a wide range of products from different clients, each with unique requirements for handling, storage, and delivery schedules (Kamali, 2019). This creates a need for highly adaptable, dynamic sortation systems that can efficiently manage frequent inbound and outbound shipments (Zhen & Li, 2022). The complexity of integrating such systems into existing legacy infrastructures raises both technical challenges and costs (Singh & Singh, 2015; Kamali, 2019). Additionally, the substantial upfront financial investment required to deploy IoT-enabled smart warehouses and real-time tracking solutions is difficult to justify for many 3PL companies, as their profit margins are typically thinner than those of eCommerce firms (Shang et al., 2012). The slow realization of return on investment (ROI) further exacerbates concerns, making it harder for 3PL companies to commit to these advanced technological upgrades (Singh & Singh, 2015).

Organizational resistance to change also plays a major role in the slow pace of IoT adoption within 3PL companies (Kamali, 2019; Singh & Singh, 2015). The logistics industry has traditionally been slow to adopt new technologies, partly due to the complexities of integrating them into well-established processes and legacy infrastructure (Zhen & Li, 2022). Employees and management alike may be reluctant to shift from traditional methods to more automated systems, fearing operational disruptions or job losses (Kamali, 2019). Without strong change management strategies, these internal barriers can stifle the adoption of IoT technologies, even when the long-term benefits are clear (Singh & Singh, 2015; Zhen & Li, 2022).

Moreover, the integration of IoT into existing legacy systems is another significant challenge. Many 3PL providers have relied on traditional logistics systems and infrastructure for decades, and upgrading these systems to accommodate IoT technology is often both costly and time-consuming. Legacy systems are typically not designed to handle the data influx and real-time processing demands of IoT devices, requiring extensive system upgrades or replacements. This transition period can lead to operational disruptions, which can be particularly detrimental for logistics companies that rely on the seamless movement of goods and services (Kamali, 2019; Zhen & Li, 2022).

Despite these challenges, the rapid pace of technological advancement in the logistics industry means that 3PL companies cannot afford to fall behind. As eCommerce companies continue to optimize their operations through IoT and other technologies, the gap between IoT leaders and laggards in the logistics sector is widening (Shang et al., 2012; Singh & Singh, 2015). For 3PL companies, failing to adopt IoT technologies could result in a loss of competitiveness as clients increasingly seek logistics providers that offer real-time visibility, faster delivery times, and more efficient operations (Kamali, 2019; Cao, 2020).

The problem, therefore, lies in the fact that while IoT has been successfully implemented in eCommerce companies to create smart warehouses and automated supply chains, 3PL companies face a more complex set of challenges that are preventing them from achieving the same level of adoption. To close this gap, 3PL providers must find ways to overcome the current barriers to IoT adoption (Zhen & Li, 2022; Greenawalt, 2024).

1.3 Research gap

While IoT technologies have already begun to revolutionize the logistics sector, there remains a critical gap in the scientific research surrounding the adoption of IoT in large, traditional third-party logistics (3PL) providers. These companies operate within highly complex networks, rely on well-established legacy systems, and face challenges that differ significantly from those encountered by eCommerce businesses. Despite the growing body of literature on IoT adoption, few studies touch upon how large 3PL companies, which must manage multifaceted supply chains for a variety of industries, can generally integrate IoT into their operations (see **Table 3**). However, none formulate a step-by-step process or framework to achieve this. On the other hand, while studies that address general technology adoption have been published throughout the past several decades, they often remain overly theoretical, overlooking the practical challenges faced by these logistics providers in real-world environments.

Many of the earlier models for technology adoption focus predominantly on organizational change management, user acceptance, or the spread of innovations through a social system without fully accounting for the complex financial and technical challenges that large 3PL companies face in IoT adoption. For instance, Lewin's Change Management Model (1947) is primarily concerned with managing the psychological and organizational processes that occur during change rather than the technical and financial intricacies of implementing advanced technologies like IoT. Similarly, Rogers' Innovation Diffusion Theory (1962), which explains how innovations spread over time within a social system, focuses on factors like communication channels and social influence but does not delve into the technical integration or financial aspects critical for large-scale IoT adoption.

More recent models, such as Venkatesh et al.'s Unified Theory of Acceptance and Use of Technology (UTAUT) (2003), emphasize user acceptance and behavior related to technology use within organizations. While UTAUT is highly relevant in understanding how individual employees or organizational stakeholders adopt new technologies, it does not adequately address the rapid pace of technological change and the complex technical and financial factors involved in IoT adoption. Therefore, while these models provide important insights into the human and organizational dimensions of technology adoption, they are insufficient when applied to the complex, large-scale, and dynamic environments in which 3PL providers operate.

The rapid pace of technological advancement today also makes these older frameworks less applicable, particularly for industries with legacy infrastructure that must be carefully integrated with new technologies. In the case of 3PL companies, the implementation of IoT systems is not just about managing organizational change or aligning the new technology with technical requirements; it is also about balancing profitability and financial sustainability in an environment where margins are tight. IoT projects often require substantial investment, from retrofitting warehouses with IoT-enabled automation to outfitting fleets with sensors that provide real-time data. These investments are difficult to justify without clear and immediate financial returns, a challenge that most existing models fail to adequately address.

Moreover, the accelerated pace of technological change has created a scenario in which technologies need to be adopted earlier in their development cycles. In the past, companies could afford to wait until technologies matured before implementing them, securing a competitive advantage by adopting fully developed solutions. However, in the modern context, waiting too long to adopt new technologies can result in missed opportunities, as newer, more advanced iterations of the same technologies become available shortly after. This rapid obsolescence cycle poses a unique challenge for 3PL companies, which are typically more risk-averse and slower to adopt emerging technologies compared to eCommerce companies. The need for a solution that allows for the earlier adoption of non-mature technologies while simultaneously addressing the potential challenges posed by such early adoption becomes essential.

Overall, the research gap identified in this study highlights the absence of a comprehensive and structured process that can guide large 3PL companies through their IoT adoption initiatives. Theoretical models of technology adoption are outdated in the context of today's rapidly changing technological environment. They fail to account for the specific complexities faced by 3PL companies with vast networks and legacy systems. A more modern approach that addresses these challenges while enabling faster adoption of new technologies is required to prevent 3PL providers from falling further behind their eCommerce counterparts in the race to harness IoT's transformative potential.

1.4 Main research question

To bridge the identified research gap, this study seeks to address the lack of a structured framework that considers the unique operational complexities faced by large third-party logistics (3PL) companies when adopting IoT technologies. As stated in the previous section, existing technology adoption models, while valuable, do not adequately capture the rapid pace of technological advancement or the challenges of integrating IoT into legacy systems, especially for companies with extensive global operations. Therefore, a more robust, adaptable solution is necessary – one that not only facilitates rapid IoT adoption but also addresses the risks associated with such large-scale technological transformations. With this in mind, the study will focus on the following main research question, which directly stems from this identified gap:

"Which structured framework can be developed for 3PL companies to adopt IoT technologies for their operations?"

This question will guide the research as it seeks to develop a solution capable of overcoming the specific obstacles 3PL companies face, ensuring that they can effectively implement IoT technologies while remaining competitive in a rapidly evolving industry.

1.5 Design Objective

Building on the research gap and main research question identified in Section 1.4, the design objective of this study is to outline a structured framework that enables third-party logistics (3PL) companies to overcome the specific challenges of adopting IoT technology. This objective is driven by the need for a practical, adaptable solution that considers the unique complexities of 3PL operations, including their reliance on legacy systems, diverse client demands, and often tight financial margins. Addressing these challenges requires a solution that is not only comprehensive but also flexible enough to apply to a range of operational contexts within the 3PL sector. As such, the core objective of the design is the following:

"Design a comprehensive framework that guides 3PL providers through each stage of IoT adoption, equipping them with a tool that outlines the steps and processes needed to navigate barriers."

The design process follows the principles of Design Science Research (DSR), which emphasizes iterative development, evaluation, and refinement. By adhering to this methodology, the study seeks to create a framework that remains adaptable to the dynamic technological landscape of the logistics sector. The design objective thus entails producing an artifact that is both actionable and resilient, allowing 3PL companies to implement IoT solutions effectively and sustain competitive advantages over time. Ultimately, this design objective supports the overarching goal of bridging the IoT adoption gap between eCommerce and 3PL providers, enabling logistics companies to leverage IoT technology to enhance operational efficiency, client satisfaction, and overall market positioning in an era of rapid technological advancement.

1.6 Thesis outline

This report outlines the development of the IoT Technology Adoption Framework (ITAF) to help third-party logistics (3PL) companies adopt IoT technologies. Chapter 2 details the research methodology, explaining the Design Science Research (DSR) approach. Chapter 3 reviews existing literature on IoT adoption, identifying key benefits and challenges, as well as previous technology adoption models, to derive a preliminary set of requirements for the design. Chapter 4 introduces the ITAF prototype, describing its five-stage process for IoT adoption. Chapter 5 presents the evaluation of the framework through expert interviews and project evaluation sheets with FedEx Europe, leading to the refinements discussed and incorporated in Chapter 6. Chapter 7 discusses the findings and explores the broader application of the ITAF, as well as provides managerial recommendations. Academic contributions, potential opportunities for future research, and the final conclusion are presented in Chapter 8.

2

Research design and methodology

This chapter provides an overview of the research methodology and foundational concepts guiding this study. First, the principles of Design Science Research (DSR) as the chosen research approach are explained. Then, the rationale behind selecting the DSR model proposed by Peffers et al. (2007) is presented, offering a comparison with other established DSR frameworks. Next, the unit of analysis, i.e., IoT technology adoption in 3PL, is introduced. The chapter also outlines the stages of the DSR methodology through a detailed diagram, emphasizing the scope of artifact development, evaluation, and revision. Next, the research questions are detailed and assigned for each DSR phase, and finally, data collection methods and ethical considerations that shape this research project are explained, ensuring alignment with academic rigor.

2.1 Design Science Research

Design Science Research (DSR) stands as a research methodology that bridges theory and practice by focusing on the creation and systematic evaluation of artifacts aimed at addressing specific, real-world problems (Peffers et al., 2007). This approach is particularly suitable for research projects where the objective is not only to understand a phenomenon but to develop practical solutions that advance both academic knowledge and industry practice. This methodology emphasizes the iterative process of designing, building, and refining artifacts, which can include models, frameworks, methods, or technologies. Given the dynamic nature of problem-solving in contemporary settings, DSR is supported by a rigorous approach to ensure that the resulting solutions are relevant, reliable, and contribute to both practical and theoretical advancements (Peffers et al., 2007).

The DSR approach aligns with the constructivist paradigm, which states that reality is constructed through social and contextual interactions (Creswell, 2016). As Creswell (2016) points out, qualitative methods allow for a deep understanding of the context in which a problem exists, therefore enriching the process of artifact creation and ensuring that the solution is tailored to the specific challenges it aims to address. This is especially significant in contexts like logistics, where technology adoption is deeply intertwined with organizational culture, processes, and stakeholder perspectives.

DSR's iterative and systematic nature also fits within broader methodological discussions on research design, as outlined by Peffers et al. (2007). The design and evaluation phases in DSR not only seek to solve practical issues but also contribute to the academic discourse by enhancing theories related to the problem at hand. Moreover, the emphasis on rigorous evaluation and validation throughout DSR ensures that the designed artifacts are both practically viable and methodologically sound (Peffers et al., 2007). This alignment between theory, practice, and methodological rigor renders DSR a fitting approach for projects aiming to develop comprehensive frameworks that have both academic significance and real-world applicability.

Rationale For Choosing Design Science Research

DSR is widely recognized and extensively studied in academia, particularly within the Information Systems (IS) field, where established frameworks offer strong guidance throughout the research process (Hevner & Chatterjee, 2010; Johannesson & Perjons, 2021; Peffers et al., 2007). For this research study, which aims to develop a structured framework for the successful adoption of IoT technologies within the 3PL context, Peffers et al. (2007) is chosen as the most suitable because of its structured, iterative approach, which aligns closely with the objectives of developing practical solutions to real-world problems. Peffers et al. (2007)'s research focuses on the systematic development and evaluation of artifacts, making it ideal for refining solutions based on practical application. In contrast, Hevner & Chatterjee (2010) emphasize a balanced integration of academic rigor and industry relevance, but their model is more abstract and less focused on providing concrete, step-by-step guidance for solution development. Their approach is also heavily theory-based, which is less fitting for research projects aimed at addressing specific operational challenges. Similarly, Johannesson & Perjons (2021) offer a highly prescriptive methodology rooted in information systems engineering, but this limits its applicability to the broader, cross-functional nature of the challenges being addressed in this study. Additionally, their framework places less emphasis on real-world evaluation and iterative refinement, which are central to the Peffers et al. (2007) model and crucial to the success of practical solutions. Thus, Peffers et al. (2007) provide the right balance of practical problem-solving, iterative refinement, and flexibility, making it the most suitable choice for guiding this research.

DSR is oriented towards addressing practical challenges through the development of artifacts (Peffers et al., 2007). In this research, the artifact in question is the IoT adoption framework, a structured tool intended to guide 3PL companies in navigating the complex landscape of implementing IoT solutions. By utilizing DSR, the framework is iteratively developed and evaluated in a real-world context – specifically, through a qualitative evaluation carried out in collaboration with FedEx Europe. This process ensures the framework is both theoretically informed and practically evaluated, ensuring its relevance and applicability to the operational realities of 3PL firms (Peffers et al., 2007).

This is further supported by Creswell (2016), which places an emphasis on context and stakeholder perspectives. As such, the company case evaluation approach ensures that the framework is not merely theoretical but grounded in real-world challenges faced by logistics companies during IoT adoption. Additionally, as emphasized by Peffers et al. (2007), the iterative nature of DSR supports the incorporation of feedback from various data sources – literature review, expert interviews, and case study insights – enabling a holistic approach to developing a practical, effective framework. This feedback loop ensures that the final framework is rigorously validated and aligns closely with both industry needs and theoretical expectations.

In summary, the DSR methodology's emphasis on developing, refining, and validating practical artifacts in a real-world context provides an ideal approach for developing a framework that addresses the specific challenges of IoT adoption within 3PL companies like FedEx Europe.

2.2 Unit of Analysis

The unit of analysis for this study, as briefly mentioned in section 2.1, is the IoT Technology Adoption Process within the context of third-party logistics (3PL), with a specific emphasis on FedEx Europe as the case study used for artifact evaluation. The selection of the IoT Technology Adoption Process as the unit of analysis directly addresses the research gap identified in Chapter 1: the lack of a structured framework for 3PL companies in adopting IoT technologies. Although the literature extensively acknowledges the potential of IoT for logistics, actionable frameworks to navigate its implementation challenges are scarce, especially for large-scale operators like FedEx Europe. This gap will be further elaborated on in Chapter 3.

This approach enables an in-depth exploration of the stages, decisions, and influencing factors involved in adopting and integrating IoT technologies within a large-scale logistics organization. The adoption process is examined as a comprehensive entity, encompassing the selection, evaluation, and implementation planning and execution of IoT solutions into existing operational workflows. The research aims to understand how these technologies can be strategically implemented to enhance operational efficiency and competitiveness in the logistics sector, all the while minimizing operational impact. This process requires the examination of several interconnected factors, including technological readiness, financial investment, and organizational change management.

Furthermore, the analysis aims to identify critical enablers and barriers impacting the success of IoT implementation in 3PL contexts, contributing to theoretical understanding, practical advancements, and relevant observations for further research. Insights gathered from the iterative design and evaluation of the artifact are expected to yield practical recommendations, ultimately offering a structured framework for 3PL companies to effectively adopt IoT technologies. This is in line with the DSR approach of developing and refining a practical, actionable framework.

2.3 DSR Methodology Diagram

The Design Science Research (DSR) methodology diagram follows the structured approach laid out by Peffers et al. (2007), making it an appropriate guiding framework for this study. The choice of Peffers' model stems from its systematic process for artifact development and evaluation, which aligns with the aim of this research to create and refine an IoT adoption framework. The adjusted DSR process for this study is captured in its entirety in **Figure 1** below.

PHASE 1: Identify Problem and Motivate

The first phase aims to identify and articulate the challenges faced by 3PL companies in adopting IoT technologies from existing literature. This phase explores how and why IoT solutions are well-suited to address and improve operational inefficiencies in logistics, highlighting the alignment between IoT capabilities and the sector's requirements. Then, through defining technology adoption challenges, the study establishes a foundational problem statement that justifies the need for a structured framework to guide IoT adoption (Peffers et al., 2007). The main input for this phase consists of current issues and pain points identified within the logistics sector through desk research. Specifically, the challenges faced by 3PL providers are examined to inform the development of a structured solution. A literature review is conducted as the primary research method to ensure that the problem definition is grounded in existing knowledge (Creswell, 2016).

PHASE 2: Define Objective of the Solution

Following the problem definition, the next stage is to outline the objective of the proposed framework. This objective is directly derived from the challenges identified in the first phase, aiming to provide structured guidance that mitigates the barriers to IoT adoption (Peffers et al., 2007). Inputs at this stage include insights from the literature on implementation challenges in logistics in particular and a review of existing frameworks or strategies addressing technology adoption. As such, insights are gathered into elements that are missing or require potential adjustments for an application in the current logistics sector. The key output is a set of requirements essential for supporting more successful IoT adoption in 3PL. This stage clarifies the purpose and expected impact of the framework, ensuring that its design is aligned with the needs of 3PL companies. The research method employed continues to be a literature review, allowing for the synthesis of various perspectives and best practices to inform the framework's goals (Creswell, 2016).

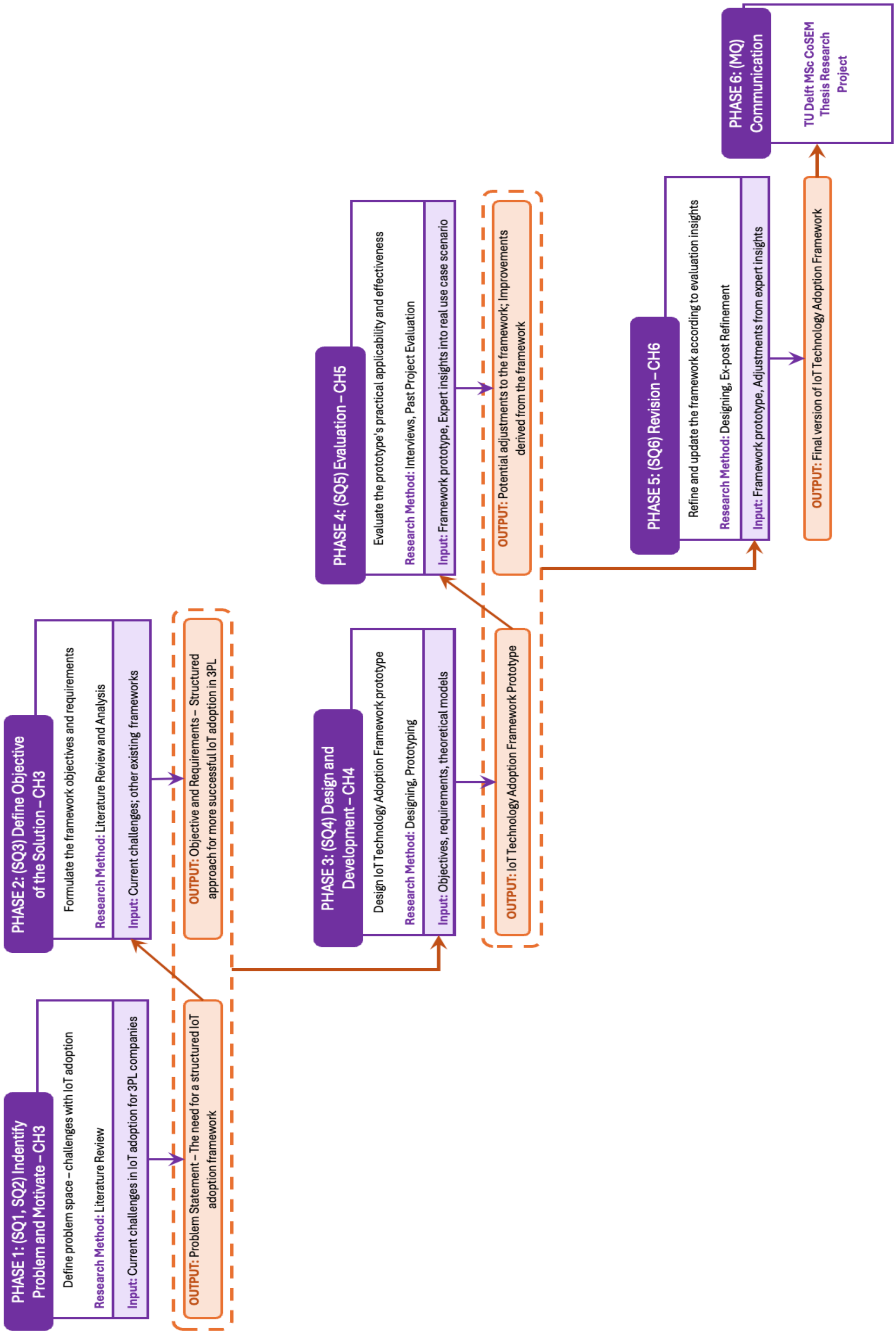

Figure 1: Design Science Research (DSR) Diagram

PHASE 3: Design and Development

The core of the DSR methodology lies in the design and development stage, where the proposed IoT Technology Adoption Framework is conceptualized. The framework is developed by synthesizing objectives, theoretical models, and practical requirements derived from the first two stages above, i.e., Identify Problem and Motivate and Define Objective of the Solution. At this point, the study seeks to create a prototype of the artifact that addresses identified challenges and meets the requirements established in the previous phase (Peffers et al., 2007). As such, the main output here is a tangible IoT Technology Adoption Framework Prototype, which provides a structured path for 3PL companies to integrate IoT into their operations effectively. As this prototype is later evaluated against the real-case scenario of FedEx Europe, it represents the primary input for Phase 4 (Peffers et al., 2007).

PHASE 4: Evaluation

The evaluation stage is essential for determining the framework's applicability in a real-world context, specifically through its implementation within the FedEx Europe case study. This stage assesses how effectively the framework addresses the complexities of IoT adoption within a large-scale 3PL operation. The evaluation is qualitative in nature, primarily based on expert insights and opinions gathered from interviews with FedEx employees, supplemented by a comparative analysis with existing FedEx processes (Creswell, 2016). Additionally, the same industry experts will retrospectively evaluate past FedEx IoT projects against the proposed framework to determine its utility and relevance. In line with Peffers et al. (2007)'s bidirectional examination, this evaluation also seeks to explore how the framework might enhance current IoT adoption processes at FedEx. The purpose of this phase is to identify and propose necessary refinements, ensuring that the framework is both theoretically sound and practically viable (Peffers et al., 2007). The key output is a set of adjustments aimed at enhancing the framework's overall effectiveness, guided by comprehensive qualitative data.

PHASE 5: Revision

In the original DSR methodology outlined in Peffers et al. (2007), revisions and refinements to the artifact are typically represented through feedback loops and process iterations, allowing for continuous improvement throughout multiple evaluations. However, due to the practical limitations of this thesis research project, a distinct revision stage is incorporated instead of continuous iteration. This revision phase consolidates adjustments observed from a single evaluation cycle, which is derived from the findings of Phase 4.

This adjusted approach enables a structured revision process, ensuring that the final framework accurately reflects both theoretical and practical feedback while remaining feasible within the constraints of the research timeline (Peffers et al., 2007). As a result, the output of this stage is a refined version of the IoT Technology Adoption Framework that integrates expert insights and arbitrary project evaluations, tailored for application within 3PL contexts. The research method continues to involve the analysis of interviews and case study data, but it emphasizes finalizing the framework based on consolidated findings rather than iterative cycles.

PHASE 6: Communication

The final stage of the DSR methodology is the communication of results, where the completed research project and its findings are documented and shared. This thesis project will be presented as part of the MSc CoSEM program at TU Delft, detailing the development, evaluation, and refinement of the IoT Technology Adoption Framework. The communication phase emphasizes the contribution of the research to both academic knowledge and practical advancements in IoT adoption within the logistics context (Creswell, 2016; Peffers et al., 2007). The structured communication ensures that the findings are accessible via the TU Delft Repository and can be utilized for further research or industry application.

2.4 Research Questions and Design Activities

Building on the principles of Design Science Research (DSR) as outlined in Section 2.1 and focusing on the IoT technology adoption process defined as the unit of analysis in Section 2.2, this section details the research sub-questions and design activities that guide this study. These elements are aligned with the stages of the DSR methodology diagram explained in Section 2.3, ensuring a cohesive and systematic approach to developing the framework (Peffers et al., 2007). The research questions and design activities are strategically formulated to address each stage of the DSR process, facilitating the iterative design, development, evaluation, and revision of the IoT Technology Adoption Framework (ITAF) for third-party logistics (3PL) companies (Peffers et al., 2007).

The primary design objective driving this study is to develop a structured framework that effectively supports 3PL companies in overcoming the unique challenges associated with IoT adoption. To achieve this, the study addresses a primary research question: *"Which structured framework can be developed for 3PL companies to adopt IoT technologies for their operations?"* This overarching question is broken down into several sub-questions and corresponding design activities, each targeting a specific aspect of the framework's development and aligned with the DSR methodology stages. These guiding components are outlined below:

PHASE 1: Identify Problem and Motivate

Design Activity: Conduct a literature review to define the problem space and justify the need for ITAF.

Sub-Questions 1 and 2:

- **(SQ 1)** *"How can the adoption of IoT help third-party logistics (3PL) companies retain relevance and competitiveness in the rapidly evolving logistics landscape?"*
- **(SQ 2)** *"What are the key challenges faced by 3PL companies in the adoption of new IoT technologies?"*

In this initial phase, a thorough literature review is conducted to explore both the strategic importance of IoT adoption for 3PL companies and the specific challenges they face (Creswell, 2016). The first research sub-question assesses the broader relevance and competitiveness that IoT can bring to logistics providers, focusing on its potential to enhance operational efficiencies, data visibility, and decision-making capabilities. This question provides foundational motivation for developing a framework by illustrating how IoT aligns with industry trends and the evolving logistics landscape.

The second sub-question narrows the focus to the specific barriers to IoT adoption, such as technological, organizational, and financial challenges, that logistics companies encounter. The literature review method involves collecting data from academic journals, industry reports, and other research studies to identify recurring issues and trends (Creswell, 2016). This phase's activities yield a comprehensive understanding of the problem, forming a basis for the artifact's design requirements (Peffers et al., 2007). By identifying both the potential benefits of IoT and the obstacles companies face, this phase establishes the need for a structured framework that helps 3PLs effectively adopt IoT. The output is a well-defined problem statement and a set of initial insights, which directly inform the objectives and requirements from Phase 2 that will guide the design (Peffers et al., 2007).

PHASE 2: Define Objective of the Solution

Design Activity: Formulate objectives and requirements for ITAF based on identified challenges.

Sub-Question 3:

- **(SQ 3)** *"What specific requirements must the framework meet to support successful IoT adoption in 3PL companies?"*

In this phase, the primary aim is to define the overarching objective of the IoT Technology Adoption Framework (ITAF) and the specific requirements it must fulfill to support successful IoT integration within 3PL companies (Peffers et al., 2007). The research sub-question is focused on identifying essential requirements that address the challenges outlined in Phase 1. This ensures that ITAF is designed to not only guide the adoption process but also to mitigate the technological, organizational, and financial barriers that 3PL companies face. The method used here is the analysis of literature sources, building on the insights gathered in Phase 1 by analyzing existing frameworks and best practices for technology adoption, specifically in logistics and related sectors (Creswell, 2016). Desk research on established technology adoption frameworks, such as the Technology-Organization-Environment (TOE) framework, Innovation Diffusion Theory (IDT), and organizational change models like ADKAR, provides insights into essential elements that ITAF should incorporate. By defining the objectives that a successful framework should achieve, as well as a preliminary set of requirements, the study positions itself to propose solutions that are both theoretically sound and practically relevant (Peffers et al., 2007). This phase's activities result in a first set of concrete design requirements, ensuring that ITAF is aligned with the industry-specific and theoretical insights identified in the research (Peffers et al., 2007). The outcome is an organized list of structural and functional requirements for ITAF, which serves as a foundation for the framework's design and development in Phase 3 (Peffers et al., 2007).

PHASE 3: Design and Development

Design Activity: Design and develop an initial prototype of ITAF based on the first set of identified requirements.

Sub-Question 4:

- **(SQ 4)** *"What are the structure and design of the necessary stages in a framework for IoT Technology Adoption in 3PL companies?"*

In Phase 3, the framework itself begins to take shape through the design and development of an initial ITAF prototype (Peffers et al., 2007). The design activity here, supported by the fourth research sub-question, addresses the specific structure and stages that ITAF should include to provide a comprehensive pathway for IoT adoption in logistics. Designing and prototyping are the methods used to translate the theoretical objectives and requirements defined in the previous phases into a tangible framework (Creswell, 2016). This involves creating a series of stages and decision points within ITAF that guide logistics companies from initial planning through full IoT implementation. The prototyping process draws from the theoretical models identified in Phase 2, incorporating elements from frameworks like TOE, IDT, and ADKAR, as well as best practices in change management and technology adoption (Creswell, 2016). The design process also integrates practical insights related to the logistics sector, such as requirements for scalability, cost management, and workforce training, which were established in the problem-definition and objective-setting phases (Peffers et al., 2007). Each stage of ITAF is crafted to address specific challenges and support critical decision points, ensuring that the framework remains adaptable to varying operational contexts. The output of this phase is a structured prototype of ITAF with clear stages, criteria, and guidelines (Peffers et al., 2007). This prototype is intended to provide 3PL companies with a roadmap that addresses the most pressing issues of IoT adoption, paving the way for practical evaluation and testing in the subsequent phase.

PHASE 4: Evaluation

Design Activity: Evaluate ITAF's applicability and effectiveness in real-life circumstances.

Sub-Question 5:

- **(SQ 5)** *"How does the IoT adoption framework perform when evaluated through a FedEx case study as a practical example of a 3PL company?"*

This phase tests ITAF's effectiveness and real-world applicability, specifically through a qualitative evaluation involving FedEx Europe (Creswell, 2016; Peffers et al., 2007). The fifth research sub-question examines how well ITAF addresses actual IoT adoption challenges in a 3PL setting, allowing for an assessment of its strengths, limitations, and areas for improvement (Peffers et al., 2007). Two methods using primary data sources – semi-structured interviews and expert evaluation sheets – are used to gather qualitative feedback from FedEx stakeholders who are directly involved in IoT implementation projects (Creswell, 2016). The semi-structured interviews provide in-depth insights by allowing participants to discuss their experiences with FedEx's current IoT processes and compare them with the framework's approach. Evaluation sheets, completed by the same participants, facilitate a structured analysis of previous IoT projects at FedEx, identifying stages in ITAF where challenges may arise or improvements could be made. These methods ensure that both open-ended perspectives and systematically gathered data inform the evaluation, offering a balanced view of ITAF's performance(Creswell, 2016; Peffers et al., 2007). The output of this phase is an analysis of qualitative data that highlights ITAF's practical utility, as well as any gaps or weaknesses that need addressing (Peffers et al., 2007). This feedback guides the necessary refinements to ITAF in Phase 5, ensuring that the framework is responsive to the realities of IoT adoption in the logistics industry (Peffers et al., 2007).

PHASE 5: Revision

Design Activity: Refine and update ITAF based on new requirements from the evaluation phase.

Sub-Question 6:

- **(SQ 6)** *"How can the IoT adoption framework be improved based on the evaluation insights to ensure it meets the operational needs of 3PL companies?"*

This phase focuses on refining and updating ITAF to ensure it aligns with the practical needs of 3PL companies, using insights gained during the evaluation phase (Peffers et al., 2007). The research question directs this phase toward improvement, highlighting the need to incorporate expert feedback to address any identified limitations or enhance framework adaptability (Creswell, 2016; Peffers et al., 2007). The method used here is ex-post refinement, where the framework undergoes targeted adjustments based on specific areas flagged during evaluation. The data gathered in Phase 4 from interviews and evaluation sheets is analyzed to identify patterns or recurring themes that indicate necessary changes (Creswell, 2016). This may include restructuring certain stages, adjusting decision points, or enhancing guidance around challenges unique to the 3PL sector, which constitute a second set of design requirements for the framework (Peffers et al., 2007). By revisiting the prototype with a focus on practical relevance, this phase ensures that ITAF meets both the theoretical and operational demands of IoT adoption (Peffers et al., 2007). The output of Phase 5 is an updated and improved version of ITAF that is better suited to guide 3PL companies in successfully implementing IoT solutions (Peffers et al., 2007). This refined framework addresses gaps and incorporates expert recommendations, enhancing its potential as a robust tool for logistics providers. The refined IoT Technology Adoption Framework then stands as the final output of this DSR cycle.

2.5 Data Collection Methods and Sources

This section details the data collection methods used for developing and evaluating the IoT Technology Adoption Framework (ITAF) for 3PL companies, following the Design Science Research (DSR) methodology. In DSR, the combination of primary and secondary data sources is essential for a well-rounded analysis of the research artifact (Peffers et al., 2007). The primary data, gathered through semi-structured interviews and expert evaluation sheets, provides direct insights into stakeholder experiences and real-world practices, enabling a practical understanding of IoT adoption challenges and effectiveness (Creswell, 2016). Secondary data sources, including academic literature and industry reports, establish the theoretical context, offering comparative insights and grounding the research within established frameworks. Together, these primary and secondary sources provide a comprehensive analysis that drives the iterative refinement of the framework, enhancing its value and applicability for 3PL companies (Peffers et al., 2007).

Literature Review

A comprehensive literature review, serving as a secondary data source, forms the foundational step in this study's data collection process. It contextualizes the research within the broader field of IoT technology adoption in logistics and highlights both common challenges as well as established best practices (Creswell, 2016). The review draws from a range of sources, including academic journal articles, industry reports, and academically recognized publications addressing technology adoption.

The purpose of the literature review is twofold: first, to identify the key challenges, benefits, opportunities, and trends in IoT adoption within the logistics context, and second, to establish a theoretical foundation for ITAF by examining relevant technology adoption frameworks. The initial phase of the review begins with an extensive search for academic and industry insights into IoT applications specific to logistics. This aims to clarify both the strategic potential of IoT and the practical challenges that companies face, covering aspects such as operational efficiency gains, real-time data tracking, and logistical coordination issues that IoT can address in 3PL environments (Creswell, 2016). Following this analysis, the literature review shifts its focus to established frameworks that inform technology adoption processes. By examining models such as the Technology-Organization-Environment (TOE) framework, the Innovation Diffusion Theory (IDT), and organizational change theories like ADKAR, the study identifies critical barriers to IoT adoption, including technological limitations and organizational resistance. The two parts of this analysis allow for the identification of gaps or limitations specific to the 3PL sector, highlighting areas where a structured IoT adoption framework could provide significant support (Peffers et al., 2007).

Additionally, consultancy reports from firms like McKinsey and Deloitte supplement academic findings by offering real-world perspectives and best practices in IoT adoption for logistics. This integration of academic and industry sources provides a balanced view, ensuring that ITAF's design is not only theoretically sound but also practically relevant to logistics-specific challenges (Peffers et al., 2007). In this way, the literature review lays a robust foundation for ITAF, addressing both the current landscape of IoT in logistics and the structural requirements for a successful adoption framework (Peffers et al., 2007).

The literature review provides inputs for multiple stages of the DSR process. It informs the identification and motivation of challenges (Phase 1), helps to define objectives for the solution (Phase 2), and provides a theoretical grounding for designing and developing the IoT Technology Adoption Framework (Phase 3) (Peffers et al., 2007). Furthermore, industry reports and white papers from leading consulting firms supplement academic findings by providing real-world insights into the challenges of IoT adoption and best practices in the logistics sector. This mix of academic and industry sources offers a robust understanding of IoT in traditional logistics (Creswell, 2016).

Interviews

To gain qualitative insights into the current IoT technology adoption landscape and assess the proposed framework, four semi-structured interviews are conducted with key FedEx stakeholders (as seen in **Table 1** below), serving as a primary data source for the framework evaluation and applicability. These stakeholders include experts fulfilling various roles across the adoption process, such as Innovations Department members, as well as implementation leads from Operation Technology central teams. The main requirement for the recruitment implies they have direct experience with IoT technology adoption within FedEx Europe. This selection ensured diverse perspectives and insights from individuals with varying levels of decision-making power, aligning with Creswell's (2016) recommendation to involve knowledgeable participants for a comprehensive view.

In preparation for data collection, extensive planning was undertaken to ensure methodological and ethical rigor. Approval was obtained from the TU Delft Human Research Ethics Committee, and a data management plan was developed. Interview questions were pre-constructed and organized into three themes: (1) evaluation of the framework, including general assessments and FedEx-specific comparisons; (2) insights into FedEx's IoT adoption landscape, with a focus on specific projects like RFID implementations; and (3) expert recommendations for the framework's broader applicability. This structure facilitates a bidirectional analysis, allowing for both targeted inquiries and open-ended discussions. A semi-structured format is chosen to provide flexibility, enabling the interviewer to delve deeper into specific areas of interest while allowing participants to freely express their experiences and perspectives (Creswell, 2016). Once confirmed, informed consent was obtained from all participants, ensuring they were fully aware of the study's purpose, their role, and their rights, including the confidentiality of their responses (Creswell, 2016).

Interviews were conducted either in person or online, depending on the availability and preference of the participants. Lasting approximately 90 minutes per session, each interview was recorded with the participant's consent and transcribed verbatim to ensure an accurate and comprehensive record of the conversation. The semi-structured interview guide allows for flexibility, enabling the interviewer to delve deeper into topics that arise during the discussion while covering all the key areas outlined in the research objectives (Creswell, 2016). After each interview, the transcripts were reviewed and coded to identify key themes and patterns related to framework revision, technology adoption processes at FedEx, and expert recommendations. This coding facilitates a focused analysis of the framework's alignment with current practices and synthesizes recommendations for its enhancement.

The qualitative data gathered through these interviews inform the design of the IoT Technology Adoption Framework (ITAF) by playing a pivotal role in the evaluation stage of the DSR process (Phase 4). By directly comparing FedEx's existing IoT adoption practices with the proposed ITAF, the interviews validate the framework's relevance and identify specific areas for improvement (Johannesson & Perjons, 2014). This process grounds the theoretical findings in real-world applications, revealing practical challenges such as unique workflows, operational bottlenecks, and technology integration issues that might not be fully captured in the literature (Creswell, 2016). Incorporating insights from key stakeholders ensures the framework is user-friendly, adaptable, and aligned with the day-to-day realities of 3PL companies, making it both actionable and feasible. Interview feedback also refines specific stages of the framework, clarifies decision points, and informs relevant metrics that are prioritized by logistics companies. This feedback-driven process supports ITAF's development as a robust and customizable tool, effectively guiding 3PL companies through IoT adoption by addressing context-specific challenges and enhancing operational alignment (Creswell, 2016; Johannesson & Perjons, 2014).

Table 1: FedEx Interviews

FEDEX INTERVIEW	COMPANY ROLE
Interview 1	Manager Innovations
Interview 2	Manager Operations Technology
Interview 3	Project Engineer
Interview 4	Senior Industrial Engineer

Expert Evaluation Sheets

Expert evaluation sheets are used to assess the proposed IoT adoption framework against FedEx's previous IoT project initiatives. The same interviewees participating in the semi-structured interviews are asked to provide an informed evaluation of past projects by completing an Excel-based evaluation sheet. Developed in advance, the sheets require participants to outline prior IoT projects at FedEx using ITAF, specify at which stage or gate within the proposed framework the project stopped or encountered difficulties, and provide the reasons for these outcomes. This approach enables participants to draw on specific project experiences to illustrate relevant successes or obstacles, thus providing concrete examples that supplement the qualitative data collected through interviews. As Peffers et al. (2007) highlight, using real-case evaluations supports the iterative refinement of DSR artifacts by grounding feedback in practical application, thereby making it highly relevant for enhancing framework alignment with real-world needs.

Participants are introduced to the evaluation sheets during their interviews and are invited to complete them if they have direct experience with or knowledge of the projects being evaluated. Each participant is given a structured template, which facilitates a clear comparison of past FedEx IoT practices with ITAF. In the final report, the names of IoT projects are anonymized for confidentiality, and only aggregate results are used to ensure privacy while providing a comprehensive view of IoT adoption challenges (Creswell, 2016). This planning ensures the collection of relevant, actionable data to support the first round of iterative design and refinement of the IoT adoption framework (Peffers et al., 2007).

Additionally, participants are asked to rate each project's success based on metrics aligned with the framework. This reflective assessment enables a critical comparison between the existing processes and the proposed structured framework, offering insights into how each project's success could have been improved by following the framework. The aggregate results also enable the reinforcement of patterns or common barriers in IoT adoption identified from the qualitative interviews, providing a deeper understanding of how well the framework can improve or guide successful IoT technology integration (Peffers et al., 2007).

This evaluation exercise contributes to both the evaluation (Phase 4) and revision (Phase 5) stages of the DSR process. By applying ITAF to past projects, the sheets provide a way to test the framework's relevance and usability in a real-world 3PL context. These past projects aim to solidify patterns regarding steps within the framework where they encountered challenges, as well as any reasons for delays, roadblocks, or discontinuation. Participants are asked to complete the sheets based on their firsthand experience with these initiatives, enabling a systematic evaluation of each project's alignment with the framework stages and criteria (Peffers et al., 2007). Given the one-time evaluation focus of this study, the exercise enables a manageable yet thorough analysis that informs the framework's final adjustments. This structured assessment ensures that ITAF is aligned with the practical realities of IoT adoption in logistics, strengthening its applicability (Peffers et al., 2007).

A full overview of the data collection methods and sources, as discussed here, is showcased in **Table 2** below:

Table 2: Overview of RQs, Data Collection Methods and Sources

RESEARCH SUB-QUESTION	DATA COLLECTION METHOD(S)	DATA SOURCE
SQ1	Literature Review	Secondary
SQ2	Literature Review	Secondary
SQ3	Desk Research (Literature Review)	Secondary
SQ4	Desk Research (Literature Review)	Secondary
SQ5	Expert Interviews	Primary
	Evaluation Sheet of Past Projects	Primary
SQ6	Expert Interviews	Primary
	Evaluation Sheet of Past Projects	Primary

Chapter Summary

This chapter established the Design Science Research (DSR) methodology as the most appropriate framework for developing and evaluating an IoT adoption framework for 3PL companies. By adopting Peffers et al. (2007), the research emphasizes a single-iteration approach to design, evaluation, and revision, assigning research sub-questions to each, and thus ensuring the solution remains adaptable and effective in real-world applications. This chapter also defined IoT adoption in logistics as the central unit of analysis and outlined the data collection methods – literature reviews, interviews, and expert evaluations of past projects – that will drive the development of the framework. Finally, ethical considerations and the role of the researcher were discussed, underscoring the balance between insider access and objectivity. This chapter sets the foundation for the DSR phases that follow in the subsequent chapters.

3

Formulating the design requirements

This chapter provides the results and insights gathered from a comprehensive review of existing literature related to the Internet of Things (IoT) and its application in the logistics sector, particularly within third-party logistics (3PL) companies. It begins with the design activity for Phase 1 in section 3.1, which involves conducting a literature review to define the problem space and justify the need for the IoT Technology Adoption Framework (ITAF). This section defines IoT, outlines its key components, and summarizes relevant technologies in the logistics industry. It also identifies the primary benefits of IoT adoption, aiming to answer sub-question 1 of this study, *“How can the adoption of IoT help third-party logistics (3PL) companies retain relevance and competitiveness in the rapidly evolving logistics landscape?”*. Additionally, this section explores the challenges associated with IoT implementation in logistics to address sub-question 2, *“What are the key challenges faced by 3PL companies in the adoption of new IoT technologies?”*.

In the second part, section 3.2, aligned with the design activity for Phase 2, the chapter focuses on formulating objectives and requirements for ITAF based on the challenges identified. This involves a review of established technology adoption models to further ground the proposed framework in scientific relevance. Building on these insights, the focus of section 3.3 shifts to defining a preliminary set of requirements for the artifact of this study, answering sub-question 3: *“What specific requirements must the framework meet to support successful IoT adoption in 3PL companies?”*. The chapter concludes with an overview of all identified requirements from the literature, providing a foundation for the design and development of ITAF.

3.1 Internet of Things

3.1.1 General Properties In Literature

The Internet of Things (IoT) refers to a network of interconnected physical objects embedded with sensors, software, and other technologies that enable autonomous data collection, exchange, and processing (Miorandi et al., 2012; Whitmore et al., 2015). As such, it combines the network aspect ("internet") and the interconnected objects ("things") that autonomously collect data (Ben-Daya, 2017; Hammoudi, 2018). By bridging the digital and physical worlds, IoT allows devices to communicate and interact with minimal human intervention, facilitating seamless data-driven decision-making and enhancing operational efficiency (Ben-Daya et al., 2017; Macaulay et al., 2015; Hammoudi et al., 2018). At its core, IoT creates a digital ecosystem where real-world objects sense their environment, monitor conditions, and interact by sending, receiving, processing, and storing information in real-time (Witkowski, 2017; Silkina & Scherbakov, 2019). This technology relies on ubiquitous sensors and actuators to transform physical objects into digitally connected entities, enabling continuous data exchanges (Witkowski, 2017; Miorandi et al., 2012).

The concept of the Internet of Things (IoT) traces back to the 1980s with the introduction of RFID technology, though it wasn't until Kevin Ashton coined the term "Internet of Things" in 1999 that the concept gained broader attention (Macaulay et al., 2015; Ivankova et al., 2020). Initially focused on object identification, IoT has since grown in scope, propelled by advancements in wireless communication, sensor technology, and cloud computing (Ben-Daya et al., 2017). These technological developments, combined with the widespread adoption of smartphones and the rollout of 4G and 5G networks, have significantly expanded IoT's capabilities, enabling faster and more reliable connectivity between devices (Ivankova et al., 2020; Whitmore et al., 2015).

As IoT has evolved, it has not only connected devices but also integrated data, people, and processes, creating a more interconnected ecosystem. This shift has generated vast amounts of data, prompting organizations to develop new business models that can handle the increasing complexity of data architecture and management (Whitmore et al., 2015; Macaulay et al., 2015). The sheer volume of data generated by IoT devices—continuously collected, transmitted, analyzed, and presented—requires sophisticated infrastructure to ensure that data can be effectively used for decision-making. IoT systems achieve this through distinct functional layers that operate in unison to streamline data flows and provide actionable insights (Whitmore et al., 2015; Macaulay et al., 2015).

IoT systems are typically composed of four main layers:

1. **Sensing Layer:** This layer includes devices and sensors that collect data from the environment. These sensors monitor various parameters such as location, movement, and temperature, providing the raw data that feeds into the IoT system (Miorandi et al., 2012; Khan et al., 2022). With advancements in sensor technology, the cost of deploying sensors has significantly decreased, making IoT more accessible across industries (Khan et al., 2022).
2. **Networking Layer:** This layer is responsible for transmitting the data collected by the sensing layer to other devices and systems. It utilizes communication technologies such as Wi-Fi, Bluetooth, and cellular networks to ensure seamless data transfer and connectivity (Whitmore et al., 2015). Recent advancements in 5G technology have improved the scalability and speed of IoT networks, enabling faster communication between devices (Ivankova et al., 2020).
3. **Service Layer:** The service layer processes and analyzes the data received from the networking layer. It includes data storage, analytics, and decision-making systems that convert raw data into actionable insights. This layer often leverages cloud computing and big data technologies to manage and analyze large volumes of data efficiently (Miorandi et al., 2012). AI and machine learning algorithms are increasingly being integrated into this layer to optimize decision-making processes (Silkina & Scherbakov, 2019).
4. **Interface Layer:** This layer provides the user interface and application interfaces that allow users to interact with the IoT system. It includes dashboards, mobile apps, and other visualization tools that present the processed data in a user-friendly manner, enabling informed decision-making (Whitmore et al., 2015; Kern, 2021). The increasing sophistication of these interfaces allows companies to visualize complex data in real time, improving operational oversight (Kern, 2021).

Rather than representing a singular technology, IoT encompasses a wide range of interconnected technologies that work together to form complex networks of communication between devices, people, and systems. While individual technologies like RFID, smart sensors, or GPS might not constitute IoT on their own, they become integral components of an IoT system when they are part of a network that facilitates data collection, exchange, and real-time analysis (Ben-Daya et al., 2017; Whitmore et al., 2015). This integration of diverse technologies underscores IoT's flexibility, allowing companies to create tailored solutions that address specific operational needs by leveraging the combined power of these connected systems (Khan et al., 2022; Macaulay et al., 2015). As these technologies work in unison, businesses can achieve capabilities such as predictive maintenance, asset tracking, and real-time analytics, ultimately contributing to more efficient and agile operations (Whitmore et al., 2015; Miorandi et al., 2012).

As IoT systems have matured, they have unlocked unprecedented opportunities for innovation and organizational transformation, making IoT a rapidly expanding field across various industries (Miorandi et al., 2012; Kern, 2021). This transformation stems from IoT's ability to generate actionable insights through the real-time analysis of vast amounts of data, enabling companies to streamline operations, optimize decision-making, and enhance customer satisfaction

(Ivankova et al., 2020; Macaulay et al., 2015). By leveraging the power of data collected across interconnected devices, IoT facilitates the automation of processes and the adoption of intelligent systems, making it a key enabler of digital transformation (Kern, 2021).

The transformative potential of IoT becomes particularly evident when applied to industries with complex, data-driven processes. One such sector is logistics, where the need for real-time data, efficient resource management, and seamless connectivity has positioned IoT as a critical enabler of innovation. In logistics, IoT technologies are used to track assets, monitor inventory, and optimize delivery routes, thereby enhancing operational efficiency and reducing costs. This integration of IoT into logistics creates new opportunities for automation, predictive maintenance, and improved decision-making, all of which are essential for staying competitive in a rapidly evolving market. The next section explores how IoT is being leveraged in logistics and examines specific technologies that are reshaping the logistics landscape.

3.1.2 IoT Technologies In Logistics

The integration of IoT technologies in logistics began gaining momentum in the early 2000s, driven by advancements in technologies such as RFID (Radio Frequency Identification), which enabled companies to track goods throughout the supply chain in real time (Witkowski, 2017). Initially, RFID and wireless sensor networks were used primarily for inventory management and cargo tracking, but as technology evolved, IoT applications expanded to include predictive maintenance, real-time data analysis, and more advanced forms of automation (Ben-Daya et al., 2017). These developments have transformed the logistics industry, allowing for greater operational efficiency and transparency (Ben-Daya et al., 2017).

As part of Industry 4.0, IoT technologies are now integral to the convergence of Information Technology (IT) and Operational Technology (OT) systems in logistics (Ivankova et al., 2020). By linking IT and OT systems, IoT enables real-time data flow between devices, machines, and management systems, facilitating more informed decision-making and automation (Ivankova et al., 2020). This has proven particularly useful in applications like fleet management and warehouse automation, where IoT technologies provide actionable insights to improve operational efficiency (Miorandi et al., 2012).

While IoT adoption in logistics has been widespread, a notable divide exists between e-commerce companies and third-party logistics (3PL) providers. E-commerce giants, such as Amazon and Alibaba, and online retailers have been at the forefront of adopting IoT technologies, using them to enhance transparency, optimize inventory management, and automate their distribution processes (Silkina & Scherbakov, 2019, Deloitte, 2021). These former companies have built highly sophisticated logistics networks driven by real-time data and automated systems. In contrast, 3PL providers, including companies like FedEx, DHL, and UPS, face unique challenges when attempting to integrate IoT technologies into their large-scale, multi-stakeholder operations (Ben-Daya et al., 2017). The complexity of 3PL networks connected by legacy systems, which often involve coordinating the activities of numerous partners, makes it more difficult to implement IoT solutions across the entire supply chain (Ben-Daya et al., 2017).

IoT technologies offer several key benefits to logistics operations, including improved visibility, enhanced asset management, and increased operational efficiency (Miorandi et al., 2012). For example, IoT devices enable logistics companies to monitor the real-time location of vehicles and shipments, track warehouse inventories, and even monitor environmental conditions that affect the transportation of goods (Ben-Daya et al., 2017). The data collected through IoT systems allows logistics managers to make more informed decisions, as well as supports optimizing routes, reducing fuel consumption, and improving delivery times (Miorandi et al., 2012). In addition, IoT-enabled predictive maintenance helps companies avoid costly downtime by detecting potential equipment failures before they occur (Hammoudi et al., 2018).

Despite these advantages, 3PL companies continue to face significant barriers to IoT adoption. High implementation costs, data integration challenges, and organizational resistance to change are among the most commonly cited obstacles (Ben-Daya et al., 2017; Whitmore, 2014; Lee, 2015). Furthermore, the complexity of integrating IoT technologies with legacy systems and the need to coordinate across multiple stakeholders make large-scale IoT implementation a difficult endeavor for 3PL providers (Ben-Daya et al., 2017; Whitmore, 2014; Lee, 2015). These challenges highlight the need for a gradual, phased approach to IoT adoption, one that simultaneously addresses the technological, financial, and organizational hurdles faced by logistics companies.

Detailed in **Table 3** is a list of the key research studies utilized for the literature review in section 3.1. These studies provide foundational insights into the role of various IoT technologies in logistics and supply chain management. Each reference contributes unique perspectives on the application, benefits, and challenges associated with specific IoT solutions, such as RFID, GPS, smart sensors, predictive maintenance tools, or middleware. The studies also explore broader themes such as the integration of IoT with legacy systems, the impact on operational efficiency, and the influence of Industry 4.0 on logistics innovation. For a full analysis of these contributions and their relevance to the technological advancements discussed in section 3.1, please refer to **Appendix A**.

Table 3: IoT in Logistics Research Papers Overview

#	Title of the Research Paper	Key Insights	IoT Technologies Addressed
1	Internet of Things (IoT) in Supply Chain Management: A Review (Ben-Daya et al., 2017)	Highlights how IoT improves supply chain efficiency through real-time data visibility, automation, and predictive insights.	RFID, GPS, Smart Sensors, AGVs, Predictive Maintenance Tools
2	Global logistics: New directions in supply chain management (8th ed.) (Fernie & Sparks, 2021)	Highlights how IoT improves supply chain efficiency through real-time data visibility, automation, and predictive insights.	General IoT in Logistics
3	Logistics and Retail Management: Emerging Issues and New Challenges in the Era of Retail 4.0 (Hassan et al., 2020)	Provides a broad discussion on challenges and opportunities in logistics without specific reference to IoT technologies.	RFID, Smart Sensors, IoT-enabled Smart Shelves
4	The Role of IoT in Supply Chain and Inventory Management (Hammoudi et al., 2018)	Focuses on real-time tracking in inventory management, enabling better stock control and reduced manual labor.	RFID, Smart Sensors, Cloud Computing
5	A Review of IoT Technologies for Supply Chain Management (Ivankova et al., 2020)	Explores communication protocols like RFID and smart sensors, and highlights cloud computing as a key enabler of IoT.	GPS, Telematics Systems
6	The Role of IoT in Logistics: A Study on GPS and Telematics Systems (Khan et al., 2022)	Analyzes the impact of GPS and telematics on fleet tracking and the enhancement of route optimization and safety measures.	AGVs / AMRs
7	Industry 4.0 and Smart Manufacturing: The Role of Automation and IoT (Kern, 2021)	Covers the automation potential of AGVs and AMRs in dynamic environments and the associated technical complexities.	Predictive Maintenance Tools
8	Predictive Maintenance Tools and Logistics Digitalization (Lee et al., 2015)	Focuses on predictive maintenance, outlining its cost-effectiveness and implementation challenges in logistics operations.	RFID, Smart Sensors, Connected Wearables, Middleware, Predictive Maintenance Tools
9	The Role of IoT in Smart Enterprises (Macaulay et al., 2015)	Discusses IoT integration in enterprises, particularly emphasizing middleware and data-driven decision-making in logistics.	Connected Wearables, IoT-enabled Smart Shelves
10	IoT in Warehousing: Real-Time Data and Wearable Devices (Miorandi et al., 2012)	Highlights the productivity and safety improvements enabled by connected wearables and IoT in warehousing environments.	RFID, Smart Sensors, Predictive Maintenance Tools
11	Internet of Things: Vision, Applications and Research Challenges (Silkina & Scherbakov, 2019)	Identifies the role of IoT in connecting physical objects to digital systems, emphasizing RFID and sensor networks.	General IoT in Logistics

12	The Logistics of Smart Supply Chains (Song et al., 2021)	Focuses on evolving logistics practices, addressing smart supply chains without direct focus on individual IoT technologies.	RFID, Smart Sensors, Middleware
13	Enabling Smart Logistics with IoT Technologies (Tang, 2020)	Analyzes how middleware improves data flow in logistics, ensuring smooth integration and communication between systems.	Cloud Computing
14	Smart Logistics Systems: The Role of IoT and Cloud Computing (Whitmore et al., 2014)	Highlights the scalability and flexibility of cloud computing in handling vast amounts of IoT data in logistics operations.	General IoT in Logistics
15	An Overview of IoT and Big Data in Logistics (Witkowski, 2017)	Discusses the intersection of IoT and Big Data in logistics, emphasizing data analytics for enhanced decision-making.	General IoT in Logistics

Beyond the overarching benefits of IoT in logistics, specific technologies offer unique applications and advantages in improving operational efficiency. **Table 4** summarizes the key IoT technologies discussed in the literature, providing an overview of their primary functions and their specific use cases in logistics operations. This table highlights how each technology is strategically employed to optimize processes such as inventory management, fleet tracking, and predictive maintenance, illustrating their critical role in modern supply chain management.

Table 4: Key IoT Technologies in Logistics

Technology	**Description**	**Use case in Logistics**
RFID (Radio Frequency Identification)	RFID utilizes electromagnetic fields to automatically identify and track tags attached to various objects. These tags store data electronically and can be read by RFID readers from a distance, eliminating the need for physical contact and making asset monitoring more efficient.	RFID is commonly used for managing inventories and tracking shipments. Logistics providers can monitor the movement of goods through warehouses, distribution centers, and delivery networks, improving accuracy and reducing manual effort.
GPS (Global Positioning System)	GPS is a satellite navigation system that offers real-time data on location and timing for GPS-enabled devices, allowing for continuous tracking of shipments, vehicle fleets, and assets in transit.	GPS is heavily used to track delivery vehicles and monitor shipments. It helps optimize delivery routes and provides real-time updates to customers, ensuring shipments reach destinations on time.
Smart Sensors/WSN (Wireless Sensor Networks)	Smart sensors collect and transmit data related to environmental conditions like temperature, humidity, or light. Wireless Sensor Networks (WSN) consist of spatially distributed sensors that work together to monitor and report conditions over a wide area.	Smart sensors and WSN are used to monitor temperature-sensitive shipments in cold chain logistics. They provide real-time updates on conditions during transit, ensuring goods remain within specified thresholds.
Telematics Systems	Telematics combines GPS tracking with on-board diagnostic tools to collect real-time data on vehicle performance, driving behavior, and fleet management, providing insights into vehicle usage, fuel consumption, and maintenance requirements.	Telematics helps optimize fleet management by tracking vehicle movements and driver behavior. It monitors routes, fuel usage, and delivery schedules in real-time, allowing maintenance needs to be addressed proactively.

Automated Guided Vehicles (AGVs)/Autonomous Mobile Robots (AMRs)	AGVs follow predefined paths using markers or wires, making them ideal for repetitive tasks in structured environments. AMRs, with advanced navigation capabilities, use sensors and cameras to independently navigate dynamic environments, offering greater flexibility in operations.	AGVs and AMRs transport goods within warehouses, moving items between storage areas and packing stations. AGVs handle heavy pallets, while AMRs perform dynamic tasks like order picking in fulfillment centers.
Connected Wearables (e.g., Smart Glasses, Wristbands)	Connected wearables, such as smart glasses and wristbands, are IoT-enabled devices worn by employees. They collect data on worker activities, health, and environmental factors, improving both productivity and safety.	Smart glasses are used for hands-free operations like order picking, where real-time instructions guide workers. Wristbands monitor employee health and safety, especially in environments with physical labor or hazards.
IoT-enabled Smart Shelves	Smart shelves are equipped with sensors that detect the presence of items, transmitting real-time data on stock levels. This technology helps businesses maintain optimal inventory levels and automate restocking processes.	In logistics and retail, smart shelves monitor stock levels and trigger automatic restocking when supplies fall below a threshold. They send alerts to inventory management systems, improving inventory accuracy.
IoT-based Predictive Maintenance Tools	These tools rely on sensors embedded in equipment to monitor performance and detect early signs of wear or malfunction, allowing companies to perform maintenance before a breakdown occurs.	Predictive maintenance tools monitor the condition of vehicles and warehouse equipment. By analyzing sensor data, companies can perform timely maintenance to prevent interruptions and minimize downtime.
Middleware	Middleware is software that serves as a bridge between different systems, devices, and applications in an IoT environment, facilitating data exchange and communication.	Middleware connects IoT devices like sensors, RFID tags, and smart shelves with ERP and warehouse management systems. This enables real-time data flow, providing visibility into operations and improving decision-making.
Cloud Computing	Cloud computing provides on-demand access to computing resources such as data storage, processing power, and software applications over the internet. It enables the collection, storage, and analysis of vast amounts of data generated by IoT devices, offering scalability and flexibility.	Cloud computing stores and processes data from IoT-enabled devices such as GPS trackers, RFID systems, and smart sensors. It is used to manage supply chain data, optimize routing, track shipments, and provide real-time updates.

By examining each of the IoT technology categories separately, we can better understand their unique functionalities, applications, and limitations within logistics. This approach allows us to identify the specific benefits and challenges associated with each technology and subsequently observe the most prevalent hurdles associated with their implementation within the logistics industry. Addressing these technologies individually also provides a clearer picture of how they interact with the distinct operational needs and constraints of 3PL companies. The next section delves deeper into specific benefits and challenges for each IoT technology of interest.

3.1.3 Key Benefits and Challenges of IoT Solutions for 3PL Operations

Building on the IoT technologies identified in the literature as particularly relevant to logistics, this section aims to break down their individual benefits and challenges in greater detail. By examining these technologies separately, we can better understand the specific advantages they bring to logistics operations and the distinct obstacles encountered during their implementation. As these challenges are explored, they will gradually be grouped into categories based on their nature. The goal of this section is to identify common patterns and develop a structured overview of the challenges associated with IoT adoption in logistics, allowing for a more comprehensive understanding of their impact on 3PL operations.

Based on the same research studies used in section 3.1.2, the literature review continues here in order to best identify the benefits and challenges associated with IoT in logistics. **Table 5** summarizes the distinct benefits associated with each IoT technology, highlighting their respective roles in enhancing supply chain visibility, reducing labor costs, improving safety, and streamlining processes. These insights provide a detailed view of how various IoT solutions contribute to the broader objectives of logistics optimization and innovation (for the full analysis, see **Appendix A**).

Table 5: IoT Benefits in Logistics

IoT Benefits	Application for Logistics	Specific IoT Technologies
(B1) Real-time tracking/monitoring	Provides the ability to monitor assets, shipments, or conditions (e.g., temperature, fleet movement) in real-time, enabling better decision-making and visibility into supply chain operations.	RFID, GPS, Smart Sensors / WSN, Telematics Systems, IoT-enabled Smart Shelves, Middleware, Cloud Computing
(B2) Improved operational efficiency	Enhances the overall efficiency of logistics operations by reducing waste, automating repetitive tasks, or enabling immediate corrective actions when issues arise.	RFID, Smart Sensors / WSN, AGVs / AMRs, IoT-based Predictive Maintenance Tools, Connected Wearables
(B3) Automation for reduced labor costs	Reduces the need for manual labor by automating processes such as stocktaking, order picking, material handling, or monitoring inventory levels.	RFID, AGVs / AMRs, IoT-enabled Smart Shelves
(B4) Enhanced resource management	Improves the management and utilization of resources (e.g., vehicles, equipment) by providing real-time data, reducing downtime, and increasing efficiency in asset utilization.	RFID, GPS, IoT-based Predictive Maintenance Tools
(B5) Improved safety	Reduces workplace hazards and improves safety for workers by minimizing human involvement in dangerous tasks (e.g., heavy lifting) or providing health monitoring (e.g., wearables).	Telematics Systems, AGVs / AMRs, Connected Wearables
(B6) Proactive maintenance	Uses IoT-enabled predictive maintenance tools to monitor the condition of equipment or vehicles, identifying potential failures before they occur to minimize downtime and extend asset lifespans.	Telematics Systems, IoT-based Predictive Maintenance Tools
(B7) Route/fuel optimization	Improves fuel efficiency and reduces operational costs by optimizing delivery routes, ensuring vehicles use the most efficient paths.	GPS, Telematics Systems
(B8) Data Storage and Processing	Provides scalable access to data storage and processing, essential for handling large volumes of IoT-generated data in logistics.	Cloud Computing

(B9) Seamless integration of devices	Facilitates the integration of various IoT devices (e.g., sensors, RFID, GPS) with logistics systems such as ERP or WMS, ensuring smooth communication and data flow.	Middleware
(B10) Increased inventory accuracy	Improves the accuracy of inventory management by using real-time data from IoT-enabled devices (e.g., smart shelves, RFID) to track stock levels and automate restocking processes.	RFID, IoT-enabled Smart Shelves

The benefits analysis based on and validated by existing literature highlights the significant advantages that IoT technologies can bring to logistics operations, making their adoption highly relevant for third-party logistics (3PL) companies. IoT can play a transformative role across various domains, including inventory and asset management (RFID, smart shelves), fleet and shipment tracking (GPS, telematics), condition monitoring and safety (smart sensors, predictive maintenance tools), warehouse operations automation (AGVs/AMRs, connected wearables), and supply chain transparency (RFID, GPS, smart sensors, telematics). Middleware enhances the seamless integration of these IoT devices with enterprise systems, ensuring real-time data flow across the logistics network, while cloud computing enables scalable data storage and processing, essential for managing the vast amounts of information generated by IoT devices.By enabling real-time visibility, proactive issue detection, and streamlined workflows, IoT supports more agile and responsive logistics management. For 3PL providers, this translates into not only more streamlined processes but also a competitive edge in an increasingly data-driven logistics landscape (Fernie & Sparks, 2021).

Similarly, the literature review also highlights challenges that companies frequently encounter when undertaking IoT adoption projects. Following a deep-dive into the research papers used for this section (see **Appendix A** for full analysis), the most common issues for each technology are outlined in **Table 6**, along with a short description. These challenges will later be condensed and grouped under broader categories for easier implementation into the design artifact.

Table 6: IoT Technologies Adoption Challenges

Technology	Challenges	Short Description
RFID (Radio Frequency Identification)	Integration with legacy systems is costly and complex. Initial infrastructure costs are high. Data management issues. User acceptance and training barriers. Interference from metals/liquids. Scalability across locations poses challenges.	Integrating RFID with old IT systems may require new hardware and software. Expanding RFID across warehouses incurs high costs, and managing large volumes of data can overwhelm systems. Metals and liquids can disrupt RFID signal accuracy. Training employees to use new RFID systems can slow adoption.
GPS (Global Positioning System)	High implementation costs for fleet systems. Signal issues in remote/obstructed areas. Data management and storage strain IT. Privacy concerns from employee tracking.	Installing GPS for fleet-wide systems can be expensive. In remote areas or urban environments with obstructions, GPS signals may be disrupted. Managing large volumes of GPS data can overwhelm IT infrastructure, and employee tracking may raise privacy concerns.
Smart Sensors/WSN (Wireless Sensor Networks)	Data management issues due to large sensor data. Installation and maintenance costs are high. Power consumption in large networks.	Installing sensors for cold chain logistics requires substantial investment, and power management for large sensor networks is challenging. Wireless interference from other devices may disrupt data collection. High

	Wireless interference from other devices.	installation and maintenance costs add to operational complexity.
Telematics Systems	High hardware installation costs. Integration with fleet systems is complex. Data management is challenging. Privacy concerns over driver behavior monitoring.	Installing telematics hardware across a fleet can be costly. Integrating telematics with existing fleet management systems requires technical expertise. Monitoring driver behavior can raise privacy concerns, and managing large amounts of telematics data presents storage and processing challenges.
Automated Guided Vehicles (AGVs)/Autonomous Mobile Robots (AMRs)	High investment for system integration. Technical complexity for dynamic environments. Ongoing maintenance costs. Employee resistance due to job displacement fears.	Integrating AGVs/AMRs into warehouses involves a large capital investment. Maintaining these systems and navigating dynamic environments increases operational complexity. Employees may resist AGV/AMR adoption due to concerns about job loss.
Connected Wearables (e.g., Smart Glasses, Wristbands)	Data security concerns, especially health data. High initial investment and training needs. Battery life issues limit productivity. Employee resistance to privacy concerns and discomfort.	Deploying wearable devices such as smart glasses requires investment and training. Workers may resist due to discomfort and privacy concerns related to health data. Battery life issues can limit the productivity of wearable devices during long shifts.
IoT-enabled Smart Shelves	High implementation costs. Complex integration with warehouse systems. Real-time sensor accuracy can be challenging. Large data volumes can overwhelm systems.	Installing smart shelves requires significant investment, and integrating with existing warehouse management systems is complex. Ensuring sensor accuracy in real time can be difficult, and managing the large volumes of data generated by the system can strain IT infrastructure.
IoT-based Predictive Maintenance Tools	Cost of monitoring equipment. Data management and system integration issues. Resistance from maintenance teams. Ongoing costs for monitoring and training staff.	Predictive maintenance tools for fleet vehicles require expensive sensors, and integrating them with existing systems is challenging. Maintenance teams may resist new workflows, and continuous monitoring and staff training lead to high operational costs.
Middleware	Interoperability issues between IoT devices and legacy systems. Expensive customization for logistics system integration.	Middleware must be customized to ensure compatibility between IoT devices and older IT infrastructure, making it costly to deploy in logistics systems.
Cloud Computing	Data security concerns in the cloud. Regulatory compliance issues (e.g., GDPR. Vulnerability to service interruptions. Vendor lock-in risks with specific providers.	Storing sensitive logistics data in the cloud raises security and compliance risks. Downtime of cloud services can disrupt operations, and relying on a specific provider can make switching vendors difficult, leading to vendor lock-in concerns.

Return on Investment (ROI) Considerations: While the benefits of IoT technologies in logistics are widely recognized, assessing the return on investment (ROI) remains a complex issue for many 3PL providers. This challenge is addressed separately here due to its applicability to more or less all IoT technologies (all are affected by this concern, but the impact can vary) and in order to avoid the repetition of similar ideas. The initial capital outlay, combined with implementation and ongoing maintenance costs, can be substantial for each of these technologies, making it challenging to justify the expenditure based on short-term gains. For instance, technologies like connected wearables, predictive maintenance tools, and smart shelves may require significant upfront investments in hardware, software, and training, while their benefits, such as cost savings from reduced downtime or improved inventory accuracy, may only be fully realized over time (Witkowski, 2017; Whitmore et al., 2014). Calculating the ROI is further complicated by the need to factor in intangible benefits, such as increased customer satisfaction or enhanced supply chain transparency, which are difficult to measure quantitatively (Witkowski, 2017). This challenge is prevalent across various IoT solutions, as each technology presents unique obstacles in terms of measuring financial returns. Consequently, these ROI concerns can hinder widespread adoption and delay implementation efforts for 3PL companies.

Culture of Innovation Considerations: Fostering a culture of innovation within 3PL companies also remains a critical challenge that affects the successful adoption and integration of IoT technologies. Many organizations struggle with resistance to change, where traditional workflows and legacy systems dominate the operational landscape, leaving little room for experimentation or the adoption of disruptive technologies. For this reason, this particular challenge is also addressed separately, as it gets examined from a general IoT perspective in current research. To illustrate, AGVs/AMRs, middleware, and connected wearables offer significant potential to enhance productivity and safety, but their implementation requires a forward-thinking mindset and a willingness to embrace change (Ben-Daya et al., 2017; Lee et al., 2015). Building a culture of innovation necessitates leadership that encourages experimentation and the adoption of new technologies, despite the associated risks. This often includes incentivizing innovation through investment in research and development (R&D), staff training, and pilot programs. However, the intangible nature of fostering an innovative mindset means that progress can be slow and difficult to measure. Companies that resist change may fail to capitalize on the long-term benefits IoT can offer, ultimately hindering their competitiveness in a rapidly evolving logistics sector (Witkowski, 2017).

Given the previously identified potential benefits, the adoption of IoT is crucial for 3PL companies aiming to modernize their operations, address their respective challenges, and stay competitive. These advantages directly answer sub-question 1 by demonstrating why and how IoT is useful for 3PL companies, and motivating its adoption to improve logistics performance. However, realizing these benefits requires overcoming a variety of challenges that have been identified for each technology. Since the successful integration of IoT solutions becomes relevant for driving operational improvements and achieving business objectives in the logistics sector, understanding and addressing these challenges is essential. The next section will categorize the prevalent challenges into main themes, providing a structured overview of the barriers to implementation. This categorization serves a dual purpose: not only to understand the nature of these challenges, but also to identify objectives and requirements for developing a framework that guides IoT adoption in 3PL companies.

3.1.4 Key Challenges in IoT Technology Implementation for 3PL

The decision to initially separate IoT in logistics into distinct technologies allowed the examination of unique benefits and challenges that each technology presents. This approach provided a detailed view of the specific hurdles companies may face when implementing different IoT solutions. However, to move from a technology-specific analysis to a more comprehensive understanding of IoT implementation in logistics, it is necessary to aggregate these findings and draw broader conclusions. Identifying common patterns and shared difficulties across the various technologies elevates the discussion to the overall IoT adoption challenges faced by 3PL providers. This transition allows for addressing the key obstacles at a strategic level and aligning the insights toward designing and developing a unified framework that supports effective IoT implementation in logistics.

In this section, the challenges are categorized based on their nature, resulting in three main categories: technical, organizational, and financial. Each category is further subdivided to capture specific aspects of the challenges, such as data interoperability, data management, employee readiness, and high implementation costs. Structuring the challenges in this manner provides a clearer understanding of the primary barriers to IoT adoption in 3PL and establishes the groundwork for formulating objectives and requirements for a robust IoT adoption framework. For now, all the insights gathered from Section 3.1.3 are included in this categorization, regardless of how many technologies they are applicable to. The summarized results of this analysis are presented in Table 7 (for the full analysis, see **Appendix A**).

Technical Challenges

Data Interoperability: Ensuring seamless data exchange across different IoT systems, as well as between the new technology and existing systems, poses a significant challenge due to varying communication protocols, data formats, and software standards. Logistics operations often involve a mix of legacy systems and newer technologies, creating difficulties in integrating disparate data sources. The lack of standardized data formats can result in data silos, making it hard to achieve a unified view of operations and requiring additional investment in middleware or data translation tools (Ben-Daya et al., 2017; Whitmore et al., 2015). For example, specific parcel data fields, such as origins/destinations or customs intercepts, can take on different formats across different systems in the architecture, which would require additional translations and could cause processing issues at various levels within the chain (Ben-Daya et al., 2017; Whitmore et al., 2015).

Technologies affected: RFID, GPS, smart sensors, telematics, predictive maintenance tools.

Data Management: IoT solutions generate vast amounts of real-time data, which can strain existing IT infrastructure if not managed properly. The continuous flow of data from sensors, RFID tags, GPS devices, and other IoT technologies requires robust data processing and storage capabilities. This challenge is exacerbated in logistics, where companies must manage diverse data types, such as location, temperature, customs requirements, and inventory status, all the while ensuring data accuracy and timeliness (Silkina & Scherbakov, 2019; Ben-Daya et al., 2017). For instance, in cold chain logistics, temperature data from smart sensors needs to be collected and processed in real-time to ensure that perishable goods are maintained within safe temperature ranges throughout transit. Any delay or inaccuracy in processing this data can result in spoilage and significant financial loss, making data management a critical concern for companies operating in this sector (Ben-Daya et al., 2017).

Technologies affected: RFID, GPS, smart sensors, telematics, predictive maintenance tools.

Data Security and Privacy: Securing data across IoT networks presents a critical challenge, as IoT systems typically operate over multiple interconnected devices and networks. The increased exposure to cyber threats raises concerns about data breaches, unauthorized access, and the protection of sensitive information. The challenge of ensuring data security is further compounded by the diverse range of devices and manufacturers involved, each with different levels of built-in security (Lee et al., 2015; Ivankova et al., 2020). For instance, in logistics operations that use RFID for tracking valuable shipments, the data transmitted between RFID tags and readers can be intercepted if not adequately encrypted, potentially allowing unauthorized access to information about the shipment's contents and location. This vulnerability highlights the need for robust encryption protocols and secure authentication mechanisms to protect data across the network (Ben-Daya et al., 2017).

Technologies affected: RFID, GPS, smart sensors, telematics, connected wearables, predictive maintenance tools.

Integration with IT Infrastructure: Incorporating IoT technologies into existing IT systems is often complex and resource-intensive. Many 3PL companies rely on legacy systems that may not be designed to handle the continuous, high-frequency data flow and advanced functionalities that IoT solutions bring. This often requires significant upgrades to IT infrastructure or the use of middleware to bridge the gap between new and old systems, which can be time-consuming and costly (Ben-Daya et al., 2017; Whitmore et al., 2015). For example, integrating predictive maintenance tools with existing warehouse management systems can present challenges, as older systems may lack the capacity to process the data generated by sensors or to support the advanced analytics required for predictive algorithms. This can necessitate substantial modifications to the existing IT infrastructure or the implementation of specialized software solutions to enable compatibility and data integration (Ivankova et al., 2020).

Technologies affected: RFID, GPS, smart sensors, telematics, AGVs/AMRs, smart shelves, predictive maintenance tools.

Scalability and Maintenance: Scaling up IoT implementations can increase operational complexity, as larger networks of interconnected devices require more frequent monitoring, updates, and maintenance. For example, predictive maintenance systems may need constant calibration, while AGVs and AMRs demand regular software and hardware upgrades to maintain functionality. This increased maintenance load can strain IT and operational resources (Ivankova et al., 2020; Silkina & Scherbakov, 2019).

Technologies affected: smart sensors, telematics, AGVs/AMRs, predictive maintenance tools.

Environmental/Operational Limitations: IoT devices used in logistics, such as sensors and RFID tags, may encounter limitations in harsh environments or in operations with challenging conditions, such as extreme temperatures, humidity, or electromagnetic interference. These conditions can impact the performance and reliability of IoT technologies, necessitating additional protective measures or specialized equipment (Whitmore et al., 2015; Miorandi et al., 2012). One example of this is GPS tracking systems, which can struggle with poor signal reception in remote areas or urban environments with dense infrastructure, such as tall buildings or tunnels. This can result in intermittent data loss or inaccuracies in tracking shipment locations, affecting the ability to monitor deliveries in real-time and necessitating the use of complementary tracking methods or signal-boosting technologies (Ivankova et al., 2020).

Technologies affected: RFID, GPS, smart sensors, telematics, AGVs/AMRs.

Organizational Challenges

Culture of Innovation: Resistance to adopting new technologies is a common issue within organizations that have traditionally relied on manual or less technologically advanced processes. This cultural resistance can be driven by skepticism towards new systems or concerns about potential disruptions to established workflows. Changing the mindset within an organization to embrace innovation requires leadership support, comprehensive training, and effective change management strategies (Ben-Daya et al., 2017; Silkina & Scherbakov, 2019).

Technologies affected: all IoT technologies, at varying degrees.

Change Management: Implementing IoT solutions involves more than just deploying new technologies; it also requires rethinking existing workflows, processes, and roles. Employees may need to adapt to new ways of working, which can be met with resistance or apprehension, especially if the transition is perceived as complex or uncertain. Effective change management practices, including clear communication, staff engagement, and support mechanisms, are essential to ensure a smooth transition (Silkina & Scherbakov, 2019; Lee et al., 2015). For example, logistics companies implementing telematics systems often face challenges in getting drivers to adopt new driving practices based on telematics data, such as adjusting routes or driving styles to improve fuel efficiency. When operators are accustomed to older practices, they may be reluctant to modify their established habits, which can hinder the telematics system's potential to optimize fleet performance (Ben-Daya et al., 2017).

Technologies affected: all IoT technologies, at varying degrees.

Employee Readiness (Training): Training employees to use new IoT technologies effectively is a significant challenge. This includes understanding how to operate devices such as RFID scanners, wearables, or telematics systems, as well as interpreting the data generated. Inadequate training can lead to underutilization of IoT solutions and limit the potential benefits. Developing comprehensive training programs and ensuring continuous learning are key considerations for overcoming this challenge (Silkina & Scherbakov, 2019; Miorandi et al., 2012). For example, when logistics companies introduce connected wearables such as smart glasses for hands-free order picking, employees may require extensive training to become accustomed to using the new technology. Without proper instruction, workers may struggle to adapt to the hands-free interface and fully leverage the functionalities of the devices, potentially resulting in lower productivity and user resistance (Silkina & Scherbakov, 2019).

Technologies affected: RFID, telematics, connected wearables, predictive maintenance tools.

Financial Challenges

High Initial Investment: The upfront costs associated with acquiring IoT technologies, including hardware, software, and installation, can be a significant barrier for 3PL companies. This is particularly true for smaller firms with limited budgets, making it difficult to justify large-scale investments in IoT infrastructure (Ben-Daya et al., 2017; Ivankova et al., 2020). Relating to the previous example, implementing AGVs or AMRs in warehouses requires not only the purchase of the automated systems themselves but also substantial investment in modifying the existing layout and infrastructure to accommodate the new technology. The need for specialized training programs for employees further increases the initial costs, which can be challenging for companies with constrained financial resources (Silkina & Scherbakov, 2019).

Technologies affected: all IoT technologies, at varying degrees.

High Implementation Costs: Beyond the initial purchase, integrating IoT solutions into existing logistics operations often involves additional expenses, such as customizations, IT system upgrades, and workforce training. These costs can quickly add up, making it challenging to manage project budgets and achieve cost-effective implementation (Silkina & Scherbakov, 2019; Miorandi et al., 2012). For instance, deploying smart sensors throughout a warehouse or distribution network requires not only the installation of the sensors but also significant upgrades to network infrastructure to handle the increased data flow. Additionally, integrating sensor data with existing systems and ensuring compatibility across different data formats may necessitate costly software customizations (Ben-Daya et al., 2017).

Technologies affected: all IoT technologies, at varying degrees.

High Maintenance Costs Post-Implementation: Once IoT systems are in place, ongoing maintenance costs can be substantial. This includes routine updates, troubleshooting, and equipment repairs or replacements (Ivankova et al., 2020; Silkina & Scherbakov, 2019). For instance, predictive maintenance systems involve ongoing costs for monitoring sensor data, recalibrating equipment, and updating algorithms to improve prediction accuracy. Additionally, ensuring the data quality remains high over time may require regular inspections and adjustments to sensor placements or configurations (Ben-Daya et al., 2017).

Technologies affected: RFID, telematics, AGVs/AMRs, predictive maintenance tools.

Difficult ROI Assessment: Justifying IoT investments can be challenging due to the difficulty in quantifying the return on investment (ROI) in the short term. While IoT solutions can deliver significant long-term benefits, the initial and ongoing costs, combined with the time required to realize the full impact, can make it hard for companies to demonstrate immediate financial gains. This uncertainty can hinder decision-making and slow down the adoption process (Ben-Daya et al., 2017; Lee et al., 2015). For example, implementing telematics systems to improve fleet management may reduce fuel consumption and maintenance costs over time. However, calculating the precise financial benefits and the payback period can be challenging, especially when considering the variability in fuel prices and maintenance schedules. This makes it difficult for companies to justify the upfront investment based on projected savings alone (Ivankova et al., 2020). In another instance, implementing predictive maintenance tools can lead to significant cost savings by preventing equipment failures and reducing downtime. However, quantifying the exact financial benefits upfront is difficult, as it involves predicting potential future breakdowns and estimating the associated costs that would be avoided. This makes it challenging for companies to justify their investments based on projected returns (Ivankova et al., 2020).

Technologies affected: all IoT technologies, for various reasons.

This detailed categorization of challenges across technical, organizational, and financial dimensions provides a comprehensive understanding of the barriers to IoT adoption in 3PL logistics and informs strategies for overcoming these obstacles.

Table 7: Technical, Operational, and Financial Challenges per IoT Technology

	Challenges	RFID	GPS	WSN	Telematics	AGVs/ AMRs	Wearables	Smart Shelves	Predictive Maint.	Middleware	Cloud Comp.
Tec	Data Interoperability				✓	✓			✓	✓	

	Data Management	✓	✓	✓	✓			✓	✓		
	Data Security and Privacy		✓		✓		✓				✓
	Integration with IT Infrastructure	✓			✓	✓		✓	✓	✓	
	Scalability and Maintenance	✓		✓		✓					
	Environmental/ Operational Limitations	✓	✓	✓		✓	✓	✓			✓
Organizational	Culture of Innovation										
	Change Management	✓				✓	✓		✓		
	Employee Readiness	✓				✓	✓				✓
Financial	High Initial Investment	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	High Implementation Costs			✓							✓
	High Maintenance Costs			✓		✓			✓		
	Difficult ROI										

The overview from the literature resources, as visible in **Table 7**, also has a notable limitation regarding newer IoT technologies, such as smart shelves, where the literature is less comprehensive due to the emerging nature of the technology. As a result, some challenges, like high implementation costs and integration with IT infrastructure, are based on limited studies and may not fully capture the breadth of issues that could arise (Hassan et al., 2020). The lack of extensive research on smart shelves means that while certain challenges can be inferred from broader IoT trends, specific insights into this technology's impact on logistics are less detailed than for the more established technologies. Also, some of the identified challenges – such as difficult ROI assessment, high implementation costs, employee readiness, scalability and maintenance, and change management – are often mentioned as applicable across all IoT technologies in the literature (Ben-Daya et al., 2017; Miorandi et al., 2012; Silkina & Scherbakov, 2019). However, specific examples mentioned in the references show that these barriers can have a more significant impact on certain technologies. For instance, predictive maintenance, telematics, smart sensors, and AGVs/AMRs frequently face scalability and maintenance issues due to the extensive networks they require (Whitmore et al., 2015). Similarly, employee readiness challenges are particularly relevant when it comes to technologies like predictive maintenance tools, telematics, RFID, and connected wearables, where specialized training is essential to maximize their potential (Ben-Daya et al., 2017; Ivankova et al., 2020).

Therefore, while the table provides a useful aggregation of the challenges across IoT technologies, there is variability in the intensity and nature of these barriers, and some conclusions may be less robust for emerging technologies like smart shelves. This limitation is considered when interpreting the findings and in the development of the IoT adoption framework.

The analysis and resulting overview of key challenges in IoT technology implementation for 3PL have highlighted the multidimensional nature of the barriers that companies face. By categorizing the challenges into technical, organizational, and financial aspects, it becomes evident that a three-dimensional approach is required to address the diverse issues associated with IoT adoption. This categorization not only provides a clearer understanding of the specific obstacles but also establishes the foundation for developing an effective IoT adoption framework. As a result, the first requirements for the framework are identified: it must account for and integrate all three dimensions – technical, organizational, and financial – to ensure a holistic and robust solution that supports 3PL companies in achieving successful IoT implementation.

This conclusion marks the end of Phase 1 in the Design Science Research (DSR) diagram by answering sub-question 2: the key challenges associated with IoT adoption for 3PL companies lie in the technical, organizational, and financial dimensions. With these requirements in place, the insights serve as input for Phase 2, where the focus shifts towards defining the objective of the solution by establishing a more detailed set of requirements for a structured IoT adoption framework.

3.2 Objective of a Structured Framework

In the first part of the literature review, the focus was on identifying requirements and considerations for IoT adoption within the logistics sector, with a particular emphasis on 3PL companies as the unit of analysis. This examination addressed the first two sub-questions of the research, where the benefits (sub-question 1) highlighted the importance of IoT for advancing logistics operations, and the challenges (sub-question 2) provided insights into the specific requirements that a framework for IoT adoption needs to accommodate, as well as the issues it must address. The insights derived thus finalized the output of Phase 1 in the Design Science Research (DSR) approach: "Identify Problem and Motivate." This phase laid the groundwork for understanding the critical factors that the framework must tackle, and the findings now serve as a foundation for this next section.

The second section of the literature review shifts toward Phase 2 of the DSR process: "Define Objective of the Solution." This phase aims to answer sub-question 3 by establishing a clear set of requirements for a framework that supports effective IoT implementation in 3PL logistics. To achieve this, established models and frameworks from the literature are reviewed, offering insights on framework structure, technology adoption strategies, and change management practices. This section will, therefore, explore proven approaches to technology adoption and organizational change, setting the stage for the framework design that integrates the logistics-specific challenges identified earlier with best practices for successful IoT implementation.

3.2.1 Structured Framework as a Solution

The adoption of IoT technologies in logistics, particularly for 3PL companies, presents both opportunities and challenges that necessitate a structured approach to ensure successful implementation. For the purpose of this study, a framework is defined as a step-by-step process that guides logistics organizations, their engineers, and managers through the adoption stages, ensuring systematic decision-making and evaluation at each phase. The multifaceted nature of IoT integration, encompassing technical, organizational, and financial considerations, makes it crucial to have a systematic process that can manage the diverse factors involved (Cooper, 1990). Without a structured framework, organizations may struggle to address the complexities of data management, high implementation costs, and employee readiness effectively. A well-defined process facilitates better risk management and resource allocation by identifying potential issues early and ensuring that investments are directed toward areas with the highest likelihood of success (Cooper, 1990).

To effectively navigate the implementation of IoT solutions, a Stage-Gate framework is particularly suitable as the foundation for a structured approach. This model divides the adoption process into distinct stages, each separated by "gates" where progress is assessed and decisions are made regarding the readiness to advance to the next phase (Cooper, 1990). By implementing a Stage-Gate framework, organizations can ensure that IoT projects are systematically evaluated at each step, allowing for the identification and mitigation of risks, as well as continuous alignment with strategic objectives. The iterative nature of the Stage-Gate process also accommodates the dynamic environment of logistics operations, enabling adjustments to be made as new challenges arise or priorities shift (Cooper, 1990). This adaptability is essential for managing the evolving requirements and complexities associated with large-scale IoT deployments.

Furthermore, for a framework to be truly effective, it must be tailored to the specific needs of the organization rather than being a theoretical construct focused solely on technology (Cooper, 1990). In the context of 3PL, companies face real-world challenges such as complex legacy IT infrastructure, diverse operational environments, and varying levels of employee readiness. While the core framework can provide a general structure applicable across different 3PL organizations, it is essential for the framework to be flexible enough to account for unique organizational factors that influence IoT adoption. The structured process can offer a general roadmap while still allowing for adaptations to the specific operational contexts and resource constraints faced by individual companies (Cooper, 1990). This flexibility ensures that the framework is robust enough to guide companies through common IoT adoption challenges while accommodating variations in organizational needs and readiness. This emphasis on tailoring the framework aligns with Cooper's (1990) argument that structured processes must be adapted to the specific context to optimize.

As such, a Stage-Gate framework adapted to the logistics sector can provide a comprehensive roadmap for 3PL companies, guiding them through the complexities of IoT implementation.

3.2.2 Other Frameworks in Literature

To inform the design of a structured framework for IoT adoption, a review of established models and frameworks in the fields of technology adoption and change management is conducted in order to draw relevant and applicable insights. Although there is no widely recognized framework specifically dedicated to IoT adoption, or specifically in the logistics field, the insights from generic technology adoption frameworks remain valuable. The models presented in **Table 8** below are still widely used and form the foundation for many other frameworks in technology adoption today. By examining these well-recognized frameworks, which have been at the core of technology adoption practices for many years, the aim is to identify key components and strategies that can be adapted to the needs and challenges of implementing IoT. This section reviews the most relevant models from the literature, focusing on their implications for structuring and facilitating the adoption process within a complex organizational environment.

Table 8: Technology Adoption Models in Literature

#	Model	Publication Title	Publication Details	Key Takeaways
1	Technology Readiness Index (TRI)	Technology Readiness Index (TRI): A Multiple-Item Scale to Measure Readiness to Embrace New Technologies	Parasuraman, A., 2000	Assesses an organization's and individuals' readiness to embrace new technologies by focusing on optimism, innovativeness, discomfort, and insecurity.
2	Technology-Organization-Environment (TOE) Framework	The Processes of Technological Innovation	Tornatzky, L. G., Fleischer, M., & Chakrabarti, A. K., 1990	Emphasizes the interplay between technological, organizational, and environmental factors in assessing technology readiness and adoption.
3	Innovation Diffusion Theory (IDT)	Diffusion of Innovations	Rogers, E.M., 1962	Explains how and at what rate new technologies spread within an organization, focusing on relative advantage, compatibility, complexity, trialability, and observability.
4	Lewin's Change Management Model	Frontiers in Group Dynamics: Concept, Method, and Reality in Social Science	Lewin, K., 1947	Describes a three-phase change process: unfreezing (preparing for change), changing (transitioning), and refreezing (stabilizing after change).
5	ADKAR Model	ADKAR: A Model for Change in Business, Government, and Our Community	Hiatt, J., 2006	Focuses on individual readiness for change through the stages of Awareness, Desire, Knowledge, Ability, and Reinforcement.
6	Kotter's 8-Step Change Model	Leading Change	Kotter, J.P., 1996	Provides a structured approach to organizational change through eight stages, including creating urgency, building coalitions, and embedding new approaches in culture.
7	Resource-Based View (RBV)	Firm Resources and Sustained Competitive Advantage	Barney, J., 1991	Emphasizes the importance of firm-specific resources as a basis for competitive advantage, focusing on valuable, rare, and inimitable resources.

8	Dynamic Capabilities Framework	Dynamic Capabilities and Strategic Management	Teece, D.J., Pisano, G. and Shuen, A., 1997	Describes the ability of a firm to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments.
9	Unified Theory of Acceptance and Use of Technology (UTAUT)	User acceptance of information technology: Toward a unified view	Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D., 2003	It provides a framework for understanding the determinants of technology adoption and user acceptance, such as performance expectancy, effort expectancy, social influence, and facilitating conditions.
10	Technology Acceptance Model (TAM)	Perceived usefulness, perceived ease of use, and user acceptance of information technology	Davis, F. D., 1989	Explains technology adoption based on two main factors: perceived usefulness and perceived ease of use, which influence the intention to use and actual usage behavior.

Technology Readiness Index (TRI): In the context of an IoT adoption framework for logistics, TRI can be used to assess the organizational readiness of 3PL companies and their workforce before embarking on IoT implementation. This early evaluation would help identify any concerns or apprehensions employees may have, as well as highlight the potential need for additional resources or training efforts (Parasuraman, 2000).

Technology-Organization-Environment (TOE) Framework: The TOE framework can inform the IoT adoption framework by providing a multidimensional approach to structuring it, thus supporting detailed planning (Tornatzky et al., 1990). In adapting the TOE for the IoT framework, the environmental dimension will be replaced with a financial dimension. This adjustment aligns with the findings from Section 3.1.4, which identified financial challenges as a critical factor for 3PL companies adopting IoT technologies.

Innovation Diffusion Theory (IDT): According to IDT, IoT technologies may inherently face lower chances of diffusion, especially due to perceived complexity, difficulty in determining tangible cost-benefit results, and challenges with integrating legacy systems. However, these barriers can be mitigated by leveraging strategies for demonstrating the practical advantages of IoT solutions (e.g., demos and pilots) (Rogers, 1962).

Lewin's Change Management Model: For the IoT adoption framework, Lewin's model provides a structured approach to managing organizational changes associated with technology implementation. It suggests that the framework should include preparatory steps (e.g., early user training), active change phases (e.g., deploying IoT solutions in phases), and strategies for embedding the changes into the organization (e.g., user feedback mechanisms) (Lewin, 1947).

ADKAR Model: The ADKAR model can inform the IoT adoption framework by structuring its approach to change management. Each element of ADKAR can be integrated into the framework to ensure that the 3PL companies and their employees are adequately prepared for IoT adoption. For example, building awareness around IoT's benefits, creating desire by showing benefits for specific operational problems, providing training to enhance knowledge and ability, and establishing feedback loops. This model also highlights the need for a thorough plan before execution to facilitate change (Hiatt, 2006).

Kotter's 8-Step Change Model: Kotter's model provides further insights for a comprehensive approach to change management, addressing both the strategic and operational aspects. The framework can be designed to build urgency around the need for IoT, foster leadership support, communicate the vision clearly, and identify opportunities for quick successes to build confidence in the new technology (e.g., demos and pilots).

Resource-Based View (RBV): For the IoT framework, RBV suggests focusing on building upon the existing strengths of 3PL companies, such as using current technologies, knowledge, and processes to integrate IoT solutions (Barney, 1991). The framework should emphasize leveraging existing resources (e.g., integration with existing IT infrastructure, as opposed to adjusting it to accommodate IoT) and capabilities (e.g., expertise in innovative technologies). It encourages an approach that builds on what is already in place, thus minimizing disruption and ensuring a smoother transition.

Dynamic Capabilities Framework: This framework emphasizes flexibility and adaptability (Teece et al., 1997), contrasting with RBV's focus on leveraging existing resources. For our IoT adoption framework, this means incorporating continuous learning and adaptive strategies, enabling 3PL companies to update skills, adjust strategies, and realign resources as technologies and market demands evolve. This approach ensures the framework remains responsive to changes and supports ongoing improvement in IoT implementation.

Unified Theory of Acceptance and Use of Technology (UTAUT): UTAUT highlights the need to focus on factors that drive acceptance and use among employees (Venkatesh et al., 2003). The IoT adoption framework can include strategies to enhance performance expectancy (e.g., demonstrating IoT's benefits through demos and pilots), reduce effort expectancy (e.g., ease of use through early training), leverage social influence (e.g., promoting success stories), and create facilitating conditions (e.g., providing necessary resources and support).

Technology Acceptance Model (TAM): Incorporating TAM into the IoT adoption framework could ensure that the perceived benefits and ease of use of IoT technologies are emphasized (Davis, 1989). It could involve demonstrating the benefits of IoT through pilots and demos to enhance perceived usefulness. Early training programs could address perceived ease of use by familiarizing employees with the technology before implementation. Incorporating user feedback loops would ensure user-centered design, allowing for continuous improvements based on actual user experiences and needs.

The analysis of established technology adoption frameworks provides a foundation of core principles that are adaptable to the logistics sector despite the absence of a dedicated IoT framework for logistics. These models contribute to the set of design requirements needed for the development of the framework, which is summarized in section 3.2.4 and formally outlined in section 3.3 (see **Appendix B** for full analysis).

3.2.3 IoT Implementation Metrics For Logistics

Building on these established models, this section examines key performance indicators (KPIs) used for evaluating IoT projects in logistics, emphasizing metrics that can guide organizations in assessing IoT implementation success across various technologies. These metrics are also contributing to the design requirements of the framework (section 3.3), and due to their relevance, they are addressed separately here.

The analysis of existing literature has revealed that defining precise Key Performance Indicators (KPIs) for IoT projects across all technologies discussed in section 3.1 for logistics is challenging due to the highly technology-specific and application-specific nature of the metrics used. Scientific research papers consistently emphasize that different IoT technologies, such as RFID, GPS, smart sensors, predictive maintenance tools, etc., each have unique capabilities and roles, necessitating distinct performance indicators. For example, Ben-Daya et al. (2017) noted that KPIs for RFID might focus on inventory accuracy and asset visibility, while GPS-related metrics are more likely to include route optimization and fuel efficiency. Similarly, Whitmore et al. (2015) discussed how smart sensors would typically be evaluated based on parameters such as temperature monitoring and condition tracking. These variations make it difficult to establish a uniform set of KPIs that would apply universally across all IoT adoption scenarios.

To address this, the framework will instead adopt high-level project evaluation metrics that capture the broader dimensions of IoT implementation success. These general metrics can be structured to encompass multiple smaller, more specific KPIs while still offering a cohesive means of evaluating the overall impact of IoT solutions. Additionally, this approach allows for adaptability within the framework, as companies can tailor the detailed metrics to align with their specific technology deployments and operational needs (Cooper, 1990). This flexibility aligns with the insights from Cooper (1990), which discusses the importance of adaptable evaluation criteria in technology adoption frameworks to account for varied organizational needs and technology roles. Thus, rather than focusing on technology-specific KPIs, this section proposes using broader metrics that assess the overall project success.

As such, the following project evaluation metrics are defined based on considerations and challenges identified in previous sections:

Implementation Process Impact on Operations

This metric evaluates the extent to which IoT adoption affects logistics processes, particularly concerning changes in workflow, operational disruptions, and resource allocation. As discussed earlier, IoT technologies like AGVs/AMRs and connected wearables can significantly impact warehouse operations by redistributing workloads and altering established workflows (Ben-Daya et al., 2017). This broader term integrates smaller, specific measures, including workflow optimization and flexibility, task efficiency, labor allocation, and service quality impacts. Essentially, it focuses on the severity of disruptive implementations when compared to existing operational metrics. For example, implementing predictive maintenance tools that rely on IoT sensors can help detect equipment failures before they happen, potentially preventing costly downtime. However, if the system generates frequent false alarms or requires extensive manual oversight to verify alerts, it can disrupt daily operations by forcing maintenance teams to constantly address non-critical issues, thereby reducing overall operational efficiency. This scenario can lead to decreased productivity and delays in key logistics activities, especially if maintenance teams are overwhelmed with false alerts that divert attention from actual critical maintenance tasks (Ivankova et al., 2020). By evaluating the overall impact on operations, this metric helps determine whether IoT technologies are genuinely enhancing logistics processes or introducing additional challenges that could diminish the project's success. If operational disruptions are substantial, it indicates a need for corrective action to ensure that the benefits outweigh any negative effects. This is supported by the principles of the ADKAR model (Hiatt, 2006), where effective change management involves ensuring minimal disruption and adjusting workflows to accommodate new technologies.

Performance Improvement

Performance improvement as a high-level metric assesses the extent to which IoT solutions lead to measurable enhancements in logistics operations. This encompasses various smaller metrics such as inventory accuracy, delivery speed, equipment uptime, and supply chain efficiency. Our earlier discussion highlighted the role of IoT in improving these aspects through technologies like RFID for inventory management, GPS for optimizing delivery routes, and so on (Ben-Daya et al., 2017; Ivankova et al., 2020). For example, deploying AGVs/AMRs in warehouse settings can improve performance by automating material handling tasks, thereby increasing the speed and accuracy of inventory movements while reducing manual labor requirements. In the opposite scenario, if the required infrastructure is not fully implemented, AGVs might frequently encounter bottlenecks or have difficulty navigating dynamic environments, which can limit the expected performance gains and require additional human intervention to resolve issues. This could reduce the efficiency improvements initially sought and indicate the need for further system optimization (Silkina & Scherbakov, 2019). This metric becomes crucial for determining whether the adoption of IoT technologies is meeting the intended performance objectives or if further optimization is necessary. This metric is in line with the principles of the Technology Acceptance Model (TAM) (Davis, 1989), where perceived usefulness is linked to actual performance improvements and user acceptance.

Technical Availability (Downtime vs. Operational Availability)

Technical availability measures the ratio between the measured amount of time IoT systems remain operational and the downtime experienced, thus indicating the reliability and resilience of these technologies (Sielaff et al., 2022). Unlike the other metrics in this section, technical availability was not previously discussed in depth, but it remains relevant for evaluating the performance of IoT devices such as smart sensors, RFID readers, and telematics systems. For logistics operations, uninterrupted availability is essential for maintaining seamless workflows, especially in real-time monitoring applications (Whitmore et al., 2015).

This metric should be assessed holistically, considering not just individual device uptime but also how failures can impact the entire system's functionality, particularly if critical components like GPS trackers or telematics systems are involved (Sielaff et al., 2022). Smaller metrics that can be incorporated here include system uptime/downtime, frequency of outages, downtime duration, and even the mean time between failures. For instance, if smart sensors used to monitor temperature in cold chain logistics experience frequent downtimes, it could jeopardize the integrity of temperature-sensitive shipments such as pharmaceuticals or perishable goods (Silkina & Scherbakov, 2019) (Witkowski, 2017). Therefore, evaluating technical availability provides insight into the readiness of IoT solutions to support logistics tasks reliably. The Dynamic Capabilities Framework (Teece et al., 1997) also supports this by emphasizing the need for systems that can adapt and maintain operational integrity under changing conditions.

Technical Capability

Technical capability evaluates an organization's ability to integrate, support, and maintain IoT solutions through its existing technological infrastructure and expertise. Previously, we identified this as a significant consideration due to the diverse requirements for integrating IoT devices, managing data flows, ensuring system interoperability, etc. (Ben-Daya et al., 2017). Specific smaller metrics that fall under this broader category include system integration readiness, IT infrastructure compatibility, data processing and storage capacity, as well as the equivalent metrics for all technical challenges presented in Table 7. For example, the integration of predictive maintenance tools may necessitate enhancements in data analytics capabilities to handle the continuous data stream generated by sensors (Miorandi et al., 2012). Similarly, integrating smart sensors for temperature-sensitive shipments may require additional hardware, such as communication modules and backup power supplies, to ensure reliable monitoring (Whitmore et al., 2015). Measuring technical capability ensures that organizations are adequately prepared to support new technologies and can identify any gaps that need to be addressed. The TOE framework (Tornatzky et al., 1990) also highlights the importance of technological capability for successful adoption, encompassing readiness and compatibility of existing infrastructure.

Organizational Capability

Organizational capability measures the readiness of a company to support IoT adoption from a human resources and management standpoint. Highlighted key considerations for this topic encompass employee training, change management, and leadership support, which were discussed earlier as critical factors for overcoming resistance to IoT adoption (Silkina & Scherbakov, 2019). Smaller metrics here include employee training completion rates, staff readiness assessments, health and safety rates, and change management effectiveness. For example, introducing connected wearables like smart glasses may require comprehensive training programs to ensure that employees can effectively use the new technology and understand the data it generates (Ivankova et al., 2020). Evaluating organizational capability provides insights into whether additional efforts are needed to foster a culture that embraces technological advancements. This aligns with multiple of the change management frameworks discussed in 3.2.2, including Lewin's Change Management Model (Lewin, 1947), the ADKAR model (Hiatt, 2006), and Kotter's 8-Step Change Model (Kotter, 1996).

Financial Capability

Financial capability assesses whether an organization has all the financial resources necessary to support full IoT implementation, scaling, and ongoing maintenance. This metric was highlighted previously as a critical barrier for many companies, especially those with limited budgets (Ben-Daya et al., 2017; Whitmore et al., 2015). It encompasses smaller metrics like budget allocation for IoT projects, funding availability for ongoing maintenance, and cost-benefit analysis results. For instance, the high costs (both initial and subsequent) associated with integrating AGVs/AMRs in warehouse operational processes may require careful financial planning to ensure that the benefits outweigh the investment (Ben-Daya et al., 2017). Assessing financial capability helps determine if an organization can sustain IoT projects in the long run or if alternative funding strategies are needed. Indeed, the Resource-Based View (RBV) (Barney, 1991) suggests that leveraging existing financial resources and assets can facilitate smoother transitions and more sustainable technology adoption.

In addition to previous analysis of IoT benefits, challenges in logistics and various theoretical frameworks, the identified project evaluation metrics offer a practical means to assess the success of IoT implementation, further informing the framework design. With these insights in place, the groundwork has been laid for defining the framework's objective in the next section, ensuring that it effectively addresses the complexities and specific needs of IoT adoption in logistics.

3.2.4 Summary of Insights for Prototype Design and Development

The analysis of various theoretical models and frameworks, as well as research articles for IoT and logistics (Section 3.1), has yielded several important requirements for designing an effective IoT adoption framework tailored for 3PL logistics companies (see **Appendix B**). As such, this section provides an overall summary that is later formalized in section 3.3. These insights are grounded in well-established principles of technology adoption and change management, ensuring that the framework is theoretically comprehensive while still addressing the specific challenges encountered by IoT in logistics. For clarity, the identified requirements are summarized and numbered below, providing a reference for later use in guiding the framework development.

To summarize the aggregate results of the literature review so far: First, a stage-gate process [1] is recommended to structure the adoption pathway, enabling iterative evaluation and risk management (Cooper, 1990). The framework must build upon established models and technology acceptance principles [2] and integrate technical, organizational, and financial aspects [3] to tackle the multifaceted nature of IoT adoption, as indicated in Section 3.1.4 and the TOE framework (Tornatzky et al., 1990).

Additionally, assessing organizational readiness at early stages [4] helps identify potential barriers and resource needs (Parasuraman, 2000). Building awareness around IoT benefits through sharing success stories [5] supports adoption by enhancing perceived value (Hiatt, 2006; Venkatesh et al., 2003). Developing a thorough implementation plan before project execution [6] is essential for proper structuring and minimizing risks (Ben-Daya et al., 2017; Whitmore et al., 2015). Fostering leadership support [7] is critical to driving change (Kotter, 1996). Clear communication of the vision helps align stakeholders [8].

Early user training can mitigate resistance and improve technology acceptance [9], as suggested by Lewin's model (Lewin, 1947), ADKAR (Hiatt, 2006), and UTAUT. Implementing pilots and demos [10] can help demonstrate practical benefits, reducing uncertainty and fostering buy-in, as supported by the IDT (Rogers, 1962), Kotter's model (Kotter, 1996), and UTAUT (Venkatesh et al., 2003). Deploying IoT in phases [11] allows for gradual adaptation, reducing disruption risks (Lewin, 1947). Incorporating user feedback mechanisms [12] ensures continuous improvement based on real-world insights (Lewin, 1947; Hiatt, 2006).

The framework should also leverage some existing resources to reduce disruption [13] (Barney, 1991) while maintaining a level of flexibility and adaptability to support ongoing learning and adjustments [14] (Teece et al., 1997). Balancing RBV's emphasis on existing capabilities with the Dynamic Capabilities Framework's focus on continuous learning ensures a safe yet adaptive approach.

These requirements, derived from established models and a literature review, provide a theoretical foundation based on technology adoption frameworks adapted to the unit of analysis of interest. The next section will explore project success evaluation metrics, aiming to establish criteria for assessing the effectiveness of IoT implementation efforts in logistics. Since a stage-gate process involves iteration and decision-making checkpoints (Cooper, 1990), defining such metrics will help provide guidelines for evaluating progress and making informed decisions along the adoption process.

3.3 Definition of Objective and Requirements

As a result of the literature analysis, three distinct categories of design requirements are observed and formulated to guide the development of the IoT Technology Adoption Framework. All of the resulting requirements from previous sections of Chapter 3 are split among these three categories according to their relevance to the framework design.

1. Design Requirements for Framework Development

Principle: Academic design for a structured framework

Description: The framework should build on established research and theoretical models to create a structured, academically grounded, and adaptable framework for IoT adoption. It should employ a structured stage-gate process, covering technical, organizational, and financial aspects while maintaining flexibility to adapt to varying conditions.

Rationale: A structured framework facilitates a systematic and sequential process for IoT adoption, providing clear guidelines that support each stage, while the multidimensional coverage addresses the complexity of IoT adoption. Grounding the framework in established academic theories ensures both theoretical rigor and practical relevance.

2. Design Requirements for IoT Adoption in Logistics

Principle: Flexible, phased approach to IoT technology adoption processes in logistics

Description: The framework should support a phased IoT adoption strategy, emphasizing company readiness, stakeholder engagement, and gradual implementation. It must include a thorough capability assessment, a timely rollout strategy incorporating change management, and preliminary testing to ensure a smooth transition to IoT adoption.

Rationale: A phased adoption strategy minimizes risks and manages integration complexities. Emphasizing readiness, stakeholder engagement, and gradual implementation increases the chances of success.

3. Design Requirements for IoT Project Evaluation

Principle: Holistic evaluation for IoT adoption project success

Description: The framework should include a high-level evaluation strategy that assesses the adoption process as a whole, enabling the identification of lessons learned and facilitating continuous improvement.

Rationale: An encompassing, high-level evaluation approach ensures that all relevant factors are considered when assessing the success of IoT projects. It facilitates the identification of areas requiring improvement and informs decision-making.

The requirements identified in earlier sections of this chapter are, therefore, assigned to these three design principles and defined in **Table 9** below.

Table 9: Preliminary Requirements for Framework Design from the Literature

Design principles	**Requirements**
Design Requirements for Framework Development	[1] **The framework <u>must</u> specify a stage-gate process needed to navigate the framework.** This requirement ensures that users can systematically progress through the framework, enabling clear decision-making checkpoints. [2] **The framework <u>must</u> build on the work of other authors and established frameworks.** This requirement aims to integrate existing knowledge and best practices into the framework, enhancing its academic and practical value. [3] **The framework <u>must</u> integrate technical, organizational, and financial aspects to tackle the multifaceted nature of IoT adoption.** This requirement ensures the various dimensions relevant for IoT implementation are addressed.
Design Requirements for IoT	[4] **The framework <u>must</u> assess technical, organizational, and financial readiness at early stages.** This requirement ensures that potential barriers are identified in a timely manner, allowing for targeted mitigation strategies.

Adoption in Logistics	[5] **The framework <u>could</u> build awareness around IoT benefits by sharing success stories.** This requirement aims to enhance adoption by demonstrating the value and practical advantages of IoT technologies. [6] **The framework <u>must</u> establish a thorough implementation plan before project execution.** This requirement ensures that the adoption process is well-structured, minimizes risks, and aligns with the organization's capabilities and resources. [7] **The framework <u>should</u> foster leadership support.** This requirement ensures that key decision-makers are committed to driving the IoT adoption process. [8] **The framework <u>should</u> clearly communicate the vision to align stakeholders.** This requirement aims to ensure that all parties understand the objectives and support the IoT initiative. [9] **The framework <u>could</u> include early user training.** This requirement prepares employees to use IoT technologies effectively, reducing resistance to change. [10] **The framework <u>must</u> utilize pilots or demos.** This requirement aims to demonstrate IoT technologies' practical benefits, reducing uncertainty and fostering acceptance. [11] **The framework <u>must</u> deploy IoT in phases.** This requirement ensures a gradual and manageable implementation process, allowing for adjustments as needed. [12] **The framework <u>should</u> incorporate user feedback mechanisms.** This requirement aims to facilitate continuous improvement based on actual user experiences. [13] **The framework <u>could</u> leverage existing resources to reduce disruption.** This requirement minimizes the impact on current operations and optimizes resource use. [14] **The framework <u>must</u> maintain a level of flexibility and adaptability.** This requirement ensures that the framework can adjust to various contexts and organizational needs.
Design Requirements for IoT Project Evaluation	[15] **The framework <u>must</u> assess the implementation process's impact on operations.** This requirement helps determine if IoT adoption is causing operational disruptions. [16] **The framework <u>must</u> measure performance improvement.** This requirement ensures that IoT adoption leads to measurable gains in operational efficiency. [17] **The framework <u>must</u> evaluate technical availability.** This requirement assesses the reliability and uptime of IoT technologies to ensure operational continuity. [18] **The framework <u>must</u> assess the company's technical capabilities.** This requirement ensures the organization has the necessary technological infrastructure and expertise to support IoT adoption. [19] **The framework <u>must</u> assess the company's organizational capabilities.** This requirement evaluates the readiness of human resources and management to support IoT adoption. [20] **The framework <u>must</u> assess company financial capability.** This requirement ensures the organization has the financial resources to support the IoT project through its entire lifecycle.

The scope of section 3.2 was to identify the objectives and subsequent requirements needed for a structured IoT adoption framework tailored to 3PL companies and, as such, answer sub-question 3. To achieve this, three design categories were established, each with a set of specific requirements, summarized in Table 9. The MoSCoW method was applied to prioritize them, following the approach described by Kravchenko et al. (2022). This prioritization technique categorizes requirements into four levels of importance: Must have, Should have, Could have, and Won't have. The "Must have" category includes essential requirements without which the framework cannot function effectively, such as specifying a stage-gate process or assessing technical, organizational, and financial readiness. The "Should have" requirements, while important, enhance rather than determine the framework's baseline functionality and include aspects such as clear communication with stakeholders and fostering leadership support. The "Could have" items add value if resources allow and include highlighting early user training or leveraging existing resources. "Won't have" requirements were deemed out of scope for this iteration but may be revisited in future versions. Applying the MoSCoW method in this way provides a balanced and targeted framework design, ensuring that immediate priorities are addressed while allowing for flexibility to adapt to future needs. Additionally, to demonstrate the origin of each requirement, the relevant references are included in the last column of **Table 9**.

Chapter Conclusion

This chapter has provided a detailed analysis of IoT's impact on logistics operations by addressing both the benefits of IoT technologies and the significant challenges to their adoption, which were categorized into technical, organizational, and financial challenges. This analysis answered sub-questions 1, *"How can the adoption of IoT help third-party logistics (3PL) companies retain relevance and competitiveness in the rapidly evolving logistics landscape?"* and sub-question 2, *"What are the key challenges faced by 3PL companies in the adoption of new IoT technologies?"*, completing Phase 1: Identify Problem and Motivate of the DSR. The design activity for this phase involved conducting a literature review to define the problem space and justify the need for the IoT Technology Adoption Framework (ITAF).

Furthermore, the chapter reviewed established technology adoption frameworks and models in the literature, identifying essential principles and requirements for developing a structured IoT adoption framework. In doing so, it addressed sub-question 3, *"What specific requirements must the framework meet to support successful IoT adoption in 3PL companies?".* This activity corresponds to Phase 2: Define Objective of the Solution of the DSR, where the design activity was to formulate objectives and requirements for ITAF based on the challenges identified in Phase 1. These insights lay the groundwork for the framework's design in the next chapter, ensuring that it addresses the specific needs and complexities presented by 3PL companies.

4 PROTOTYPE DESIGN

The previous chapters explored how the complexities of IoT technology adoption in logistics require a structured and methodical approach. Through the literature review, it became evident that the diverse challenges associated with IoT implementation – spanning technical, organizational, and financial aspects – necessitate a comprehensive framework to guide companies through the adoption process. The requirements and design principles identified in Chapter 3 laid the groundwork for such a framework by establishing essential criteria for success. Chapter 4 will build on these insights. First, a high-level overview of the stage-gate framework will provide context to the overall process, establishing the sequence and purpose of each stage in guiding 3PL companies through IoT adoption. Following this, each stage will be examined in detail to clarify the specific considerations, deliverables, and decision points that characterize the structured adoption pathway proposed in the framework. The prototype for the **IoT Technology Adoption Framework (ITAF)** presented in this chapter serves as a roadmap to ensure a smooth, structured transition from identifying challenges to large-scale implementation of IoT solutions. This phase of the DSR methodology, Phase 3: Design and Development, involves the design activity of creating and developing an initial prototype of ITAF based on the requirements defined in the previous phases. The purpose of this activity is to address sub-question 4 of this study: "*What are the structure and design of the necessary stages in a framework for IoT Technology Adoption in 3PL companies?"*.

The purpose of this framework is to guide logistics companies through a systematic, stage-gated process that mitigates risks and maximizes the success of IoT solutions. By addressing technological, organizational, and financial challenges since the beginning, this framework ensures that companies are equipped to handle the complexities of IoT adoption, from pilot testing to full-scale deployment. Ultimately, this framework can help logistics companies, their engineers, and managers make informed decisions about IoT technology, ensuring alignment with strategic objectives while delivering operational improvements and measurable returns.

4.1 Stage-Gate Process for IoT Technology Adoption

The Stage-Gate Process is a structured framework for managing innovation and technology adoption, beneficial for navigating complex projects like IoT implementation in logistics. Originally developed for product development, the Stage-Gate process breaks down the adoption lifecycle into distinct phases, with decision points (gates) between each stage to assess whether to continue, adjust, or abandon the project (Cooper, 1990). This process has become widely recognized as an effective tool for reducing risk and improving efficiency in complex technology rollouts (Cooper, 1990).

In the context of IoT adoption in 3PL companies, the Stage-Gate process provides a robust method to address the unique technological, organizational, and financial challenges identified earlier in Chapter 3. By following the stages of Ideas, Readiness, Planning, Pilot, and Implementation (depicted in **Figure 2**), logistics providers can systematically evaluate the feasibility of IoT solutions, ensure organizational readiness, formulate and communicate a holistic strategy, conduct pilot projects to validate expected results, and, finally, scale up successful implementations. This is in line with requirements [1] and [2]. Each stage requires specific deliverables grouped under high-level technology adoption metrics to ensure the solution's suitability, thereby minimizing risks associated with large-scale deployments.

A notable limitation of the ITAF prototype is the lack of clear insights into stakeholder ownership at each decision gate. While the literature emphasizes the importance of defining roles and responsibilities, it does not provide specific criteria for determining which stakeholders should have ownership at different decision points. Similarly, the duration of time allocated to each stage presents another limitation, as the literature does not offer concrete benchmarks or guidelines for setting appropriate timelines.

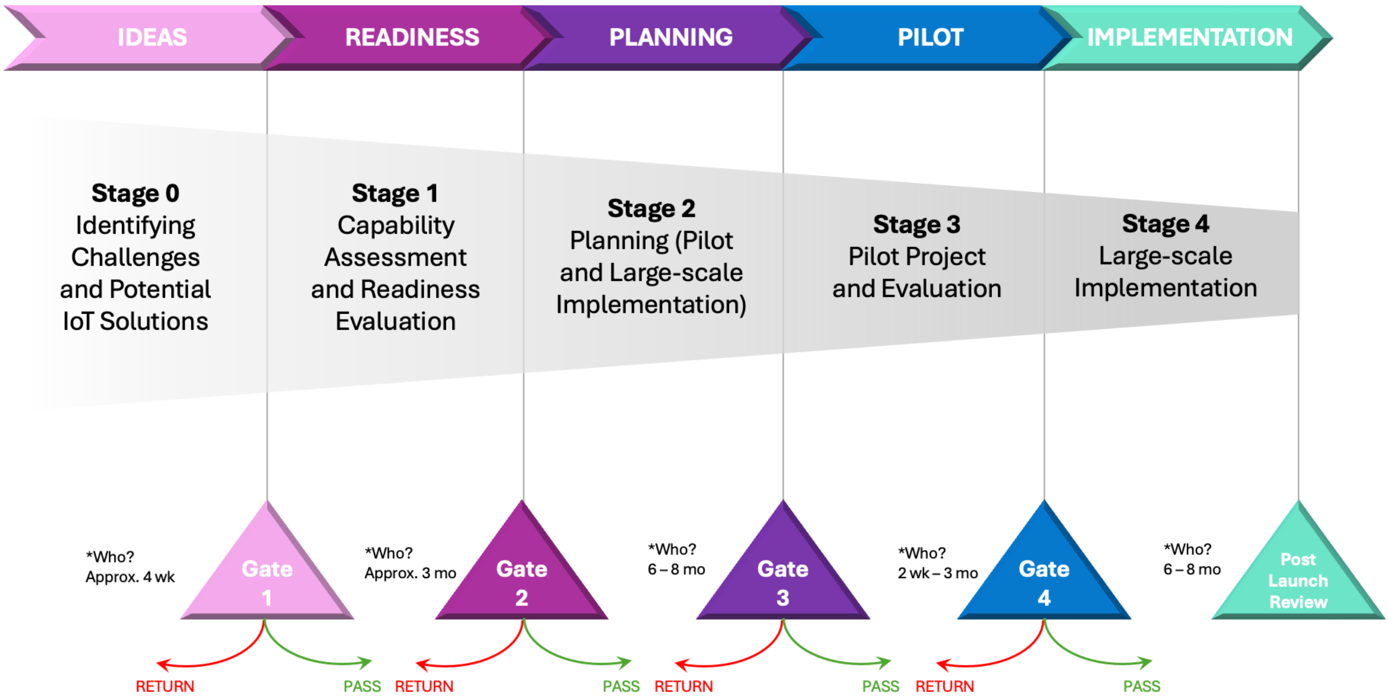

Figure 2: Stage-Gate Process for IoT Technology Adoption

Building on the requirements [15] – [20] defined in Chapter 3, this thesis proposes the evaluation of the IoT project at the gates and during the post-launch review be carried out based on six key metrics:

1. Technical Capability – How well the IoT technology performed in a real-world environment and integrated with the company's existing technology infrastructure (Ben-Daya et al., 2017; Miorandi et al., 2012).
2. Organizational Capability – How effectively the workforce adapted to and utilized the new technology, leveraging established models for change management (Silkina & Scherbakov, 2019).
3. Financial Capability – Whether the project remained within budget and if the financial returns met the expectations (Ben-Daya et al., 2017; Whitmore et al., 2015).
4. Technical Availability – The reliability and uptime of the IoT solution during its operation (Sielaff et al., 2022).
5. Implementation Process Impact – The effectiveness of the deployment process, including assessing changes in workflow, operational disruptions, and smooth integration (Ben-Daya et al., 2017). It is noted here that the impact assessment is inversely proportional to the project's success (high impact decreases the success factor and vice versa).
6. Performance Improvement – The extent to which the IoT solution improved operational efficiencies and reduced costs (Ivankova et al., 2020; Ben-Daya et al., 2017).

The resulting radar chart, as depicted in **Figure 3** below, provides a visual representation of the project's performance across these six dimensions. For the purpose of this research, ratings range from 0 to 5 for each metric (0 being the lowest, indicating that the metric cannot be observed at all or completely fails, and 5 being the highest, indicating that

it exceeds expectations). However, the ratings are arbitrary and can be adjusted to meet specific user needs. It is also important to note that the rating for the implementation process impact should be inversely proportional to its assessment: a high impact score, indicating significant disruptions or challenges, would correspond to a lower rating on the chart. This approach ensures that the radar chart effectively captures the project's overall performance across all metrics. As such, the visual representation is also useful for comparing multiple projects, allowing for the identification of performance gaps or opportunities for improvement.
With an overall idea of the framework in mind, the remaining sections in Chapter 4 will examine each stage of the proposed ITAF prototype in detail, exploring how it applies to the unit of analysis. Breaking down each stage will highlight the key considerations, deliverables, and decision points at every step of the process. This structured approach will ensure a complete understanding of how to navigate the complexities of IoT integration effectively.

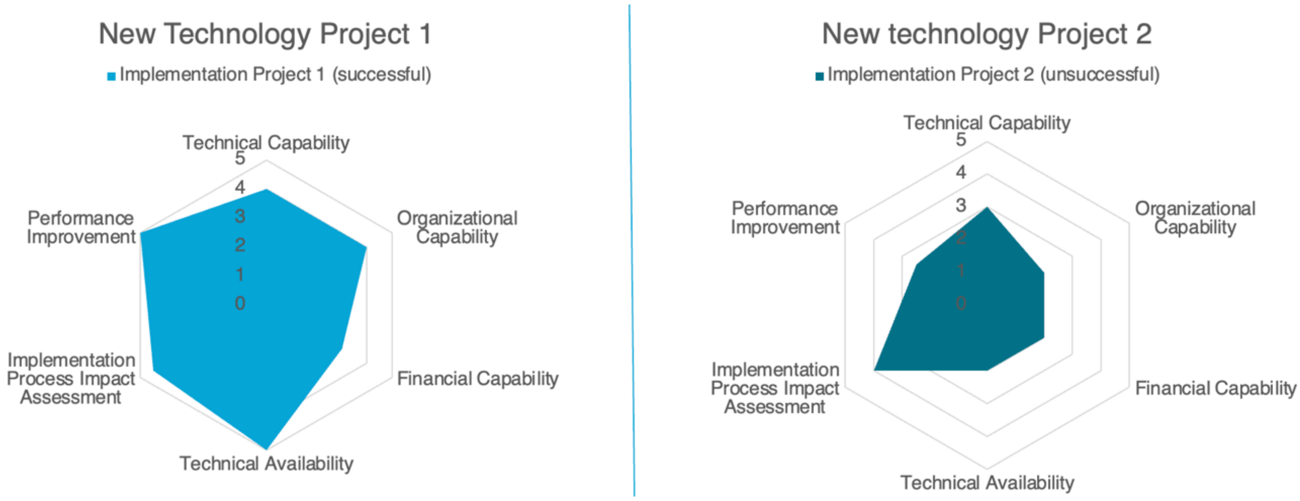

Figure 3: Project Evaluation Metrics Radar Chart (using dummy project examples)

For the step-by-step visualization of each stage, the following diagram legend helps clarify the meanings of shape colors, and arrows used to represent various steps and relationships in the IoT adoption framework.
Steps:

- **Blue shapes** represent steps that are primarily dependent on the organization itself. These include activities such as identifying challenges, assessing capabilities, and formulating strategic plans.
- **Pink shapes** indicate steps directly related to the IoT solution or technology, such as IoT solution enhancements, evaluating the expected ROI from IoT investments, or executing IoT pilot projects.
- **Orange shapes** highlight steps that involve external stakeholders outside the immediate IoT adoption team. These steps include gathering input from operations or vendors and communicating the implementation plan with other relevant parties.
- **Green shapes** are used to represent the technology-specific Key Performance Indicators (KPIs), which need to be defined by the project team based on their specific needs.

Relationships:

- **Continuous blue arrows** show the natural flow of steps within the same stage of the process.
- **Double-ended blue arrows** indicate a dependency between two steps, where the outcome of one step is linked to the other.
- **Interrupted blue arrows** suggest that the relationship between steps is not exclusive to the framework. For example, identifying operational challenges may rely on external stakeholder input (e.g., user feedback, leadership insights) but can also be influenced by other factors outside the scope of the framework, such as market changes or cyberattacks.
- **Green arrows** represent a successful movement from one stage to the next, indicating progress through the IoT adoption framework.
- **Red arrows** signal the need for revision, pointing to areas where steps must be revisited and improved based on feedback or evaluation.

Each interrupted arrow will be further explained in detail at its corresponding stage to clarify any external influences.

4.2 Framework Stage 0: Identifying Challenges

Stage 0 serves as the foundational step in the IoT adoption framework, acting as a prerequisite to initiating the technology implementation process. The purpose of this stage is to ensure that projects are selected based on their potential to address the company's most pressing operational challenges, thus avoiding the allocation of time and resources to initiatives that may not be critical. By prioritizing projects that are deemed vital, companies can focus on opportunities with the highest impact for mitigating existing challenges or creating substantial benefits.

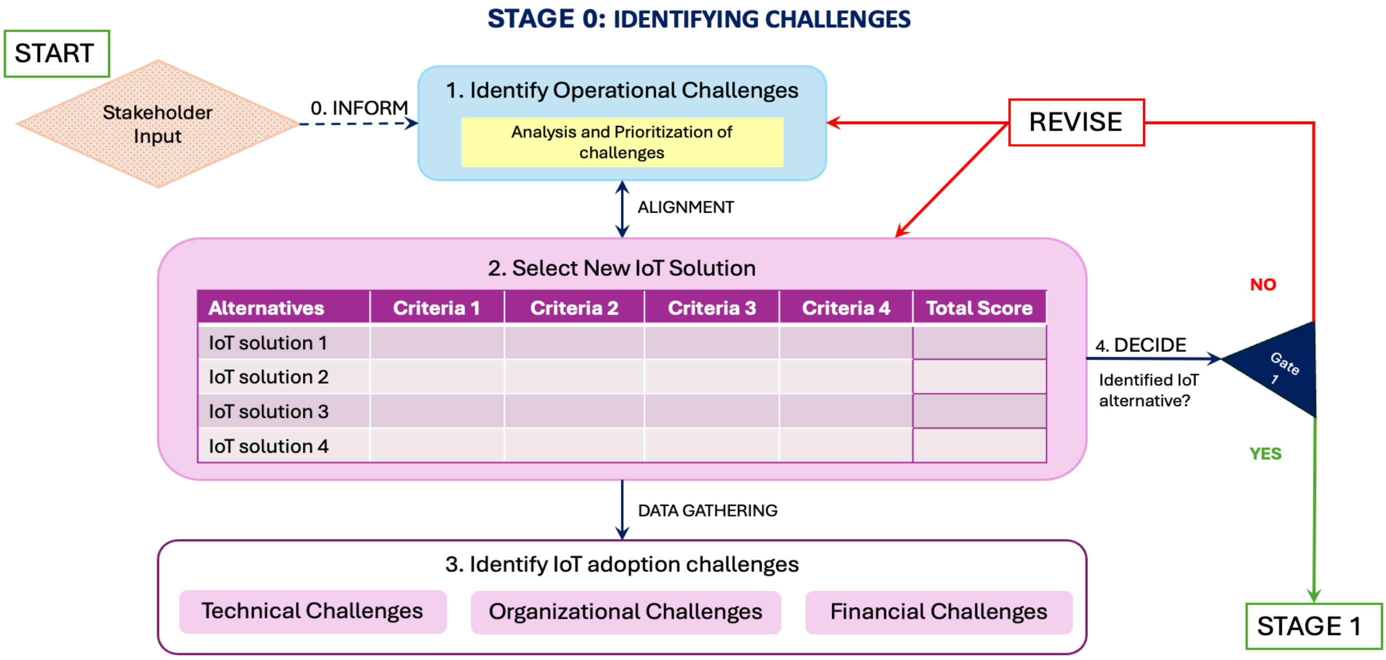

Figure 4: ITAF Prototype Stage 0 Diagram

Elements and Steps in Stage 0 (a full overview is depicted in **Figure 4**):

Step 1: Identifying and Prioritizing Operational Challenges – The first step involves identifying the company's key operational challenges and prioritizing them based on their urgency and impact. This step is informed by stakeholder input, including user feedback (requirement [12]) and insights from leadership or management (requirement [7]). Input from various organizational levels helps to ensure a comprehensive view of the company's pain points, enabling a more accurate prioritization of challenges.

Step 2: Identify IoT Solutions for Mitigating Challenges – Once the high-priority operational challenges are determined, the next step is to identify potential IoT solutions whose benefits could help address these issues. It is essential to consider multiple IoT alternatives and select the best solution using a decision matrix tailored to the specific operational challenge (requirement [14]). The criteria in this decision matrix should be case-specific, allowing for flexibility depending on the nature of the challenge and the expected impact of the IoT solution.

Step 3: Identify Adoption Challenges for the Selected IoT Solution – After choosing the most suitable IoT solution, the potential challenges associated with adopting this technology should be identified and categorized into three groups: technical, organizational, and financial (requirement [3]). This classification provides a structured approach to understanding the different aspects of the adoption process, setting the stage for a thorough and easier to conduct capability assessment in the following stage (Stage 1).

Gate 1 Decision: Has an appropriate IoT alternative been identified? – At Gate 1, the selected IoT solution from Step 2 is evaluated for its potential fit as a technological solution that can effectively mitigate the identified operational challenges. If the IoT benefits align well with addressing these challenges, the project progresses to Stage 1. Otherwise, the identified operational challenges and IoT alternatives need to be reviewed and revised.

Relationships (arrows):

- The identification of operational challenges depends primarily on stakeholder input, such as feedback from users and leadership insights. However, it can also be informed by other sources, such as poor performance indicators or unsatisfactory financial returns, as indicated by the dotted line in **Figure 4**.
- Operational challenges and IoT solutions are interdependent. The selection of IoT technologies is based on their potential to address these challenges, which, in turn, influences the reconsideration of operational needs.
- IoT adoption challenges are largely specific to the chosen IoT solution, so they are directly influenced by the characteristics and requirements of the selected technology.

Deliverable: The outcome of Stage 0 is a selected IoT solution that offers the highest expected benefits for addressing the company's prioritized operational challenges. This solution sets the course for the subsequent stages of the IoT adoption process.

4.3 Framework Stage 1: Capability Assessment And Readiness Evaluation

Stage 1 focuses solely on evaluating the company and its ability to carry the project to full completion. This ensures that resources are not wasted on projects that may be abandoned at later stages without delivering any tangible benefits. The goal here is to "fail early, fail safe" by minimizing risks while the necessary efforts and investments are still limited. This approach is essential since failing at Stage 1 is far less costly than encountering challenges in later stages, where capital and operational investments are significantly higher. The input for this stage includes the identified IoT solution, along with its preliminary adoption challenges defined in Stage 0.

Elements and Steps in Stage 1 (a full overview is depicted in **Figure 5**):

Step 1: Determine and Categorize Capabilities – To address all the identified preliminary adoption challenges, the company must evaluate three main categories of capabilities: technical, organizational, and financial capabilities (requirements [2] and [4]). Leadership should typically be responsible for defining these capabilities and establishing the assessment criteria (requirement [7]). This categorization helps ensure a comprehensive evaluation of the company's readiness to support the IoT project.

Step 2: Capability Assessment – Each category (technical, organizational, and financial) is evaluated to determine if the company can support the full-scale implementation of the IoT project. The assessment should take into account the smaller, specific challenges identified in Chapter 3, Section 3.1.3, which apply to the selected IoT solution (refer to Table 6). These could include technical factors like data interoperability and IT infrastructure integration, organizational factors such as employee readiness and change management, as well as financial factors like initial investment and maintenance costs.

Gate 2 Decision: Can the company afford the technology? – The capability assessment results inform this decision by evaluating whether the company is equipped to support the project through all subsequent stages until full implementation. If the assessment indicates sufficient capabilities, the project can proceed to Stage 2. Otherwise, the company may need to reconsider the IoT solution or reallocate resources.

Relationships (arrows):

- The technical, organizational, and financial capabilities directly inform the capability assessment.
- The results of this assessment then determine the decision at Gate 2.

Deliverable: Approval to proceed past this stage implies there are no significant blockers related to company capabilities. While small adjustments to resource allocation may still arise in later stages, the thorough assessment at this stage should eliminate the possibility of any major company capability-related issues affecting the project's progression.

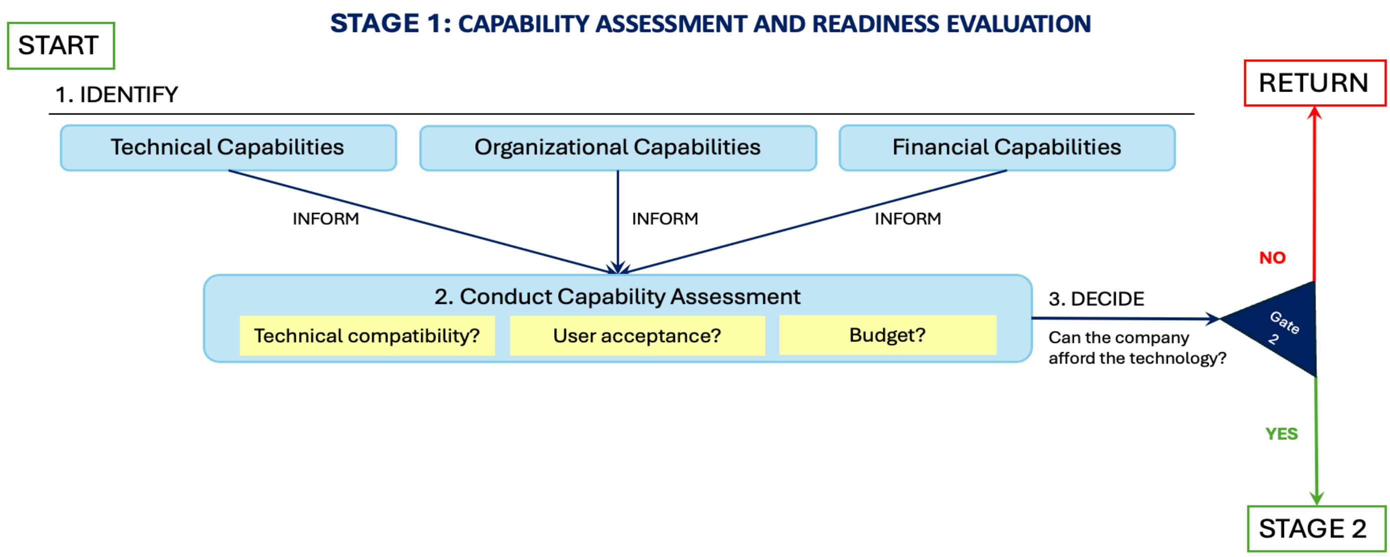

Figure 5: ITAF Prototype Stage 1 Diagram

4.4 Framework Stage 2: Planning

At Stage 2, the emphasis shifts from assessment to developing a comprehensive plan (requirement [6]) for implementing the IoT solution across the entire project scope. Proper planning before execution is crucial for minimizing efforts at later stages and avoiding the waste of resources (Ben-Daya et al., 2017). Given the topic of new technology, troubleshooting and fine-tuning are inevitable, but the scale of these activities can be significantly reduced with thorough planning (Whitmore et al., 2015). Therefore, at this stage, the planning should address both the pilot phase and the full-scale implementation.

Elements and Steps in Stage 2 (a full overview is depicted in **Figure 6**):

Step 1: Define Planning Requirements – The planning details should cover both the pilot phase (requirement [10]) and the large-scale rollout (requirement [6]). This includes setting expected results and returns, defining key performance indicators (KPIs), and establishing a preliminary goal. The goal should reflect appropriate outcomes; if set too high, it may be unachievable, while if set too low, it may not sufficiently demonstrate the value added in addressing the company's operational challenges identified in Stage 0.

Step 2: Incorporate Capability Assessment Results – Integrate the outcomes of the assessment from Stage 1 to inform the planning. This step ensures that the plan aligns with the company's capabilities, addressing key considerations, the identified challenges, and available resources.

Step 3: Develop Implementation Plan – As mentioned previously, a detailed implementation plan for both the pilot phase (requirement [10]) and the large-scale rollout needs to be formulated. This framework proposes that the large-scale rollout should follow a gradual implementation strategy (requirement [11]), but the specifics depend on the company's context, project scope, and the characteristics of the selected IoT solution (requirement [14]). Key elements to consider include but are not limited to: vendor alignment, necessary development or customization work, resource allocation (requirement [13]), user training (requirement [9]), ownership roles, timelines, and change management.

Step 4: Communicate the Plan – The formulated plan should be clearly communicated to all relevant stakeholders to ensure alignment and shared understanding of the project's direction (req [8]).

Gate 3 Decision: "Is the planning complete and within the company's capabilities?" – If the answer is yes, the project can proceed to Stage 3. If not, the company needs to revert to earlier stages to resolve identified issues, e.g., returning to Stage 1 for a reassessment of capabilities if additional resources are needed.

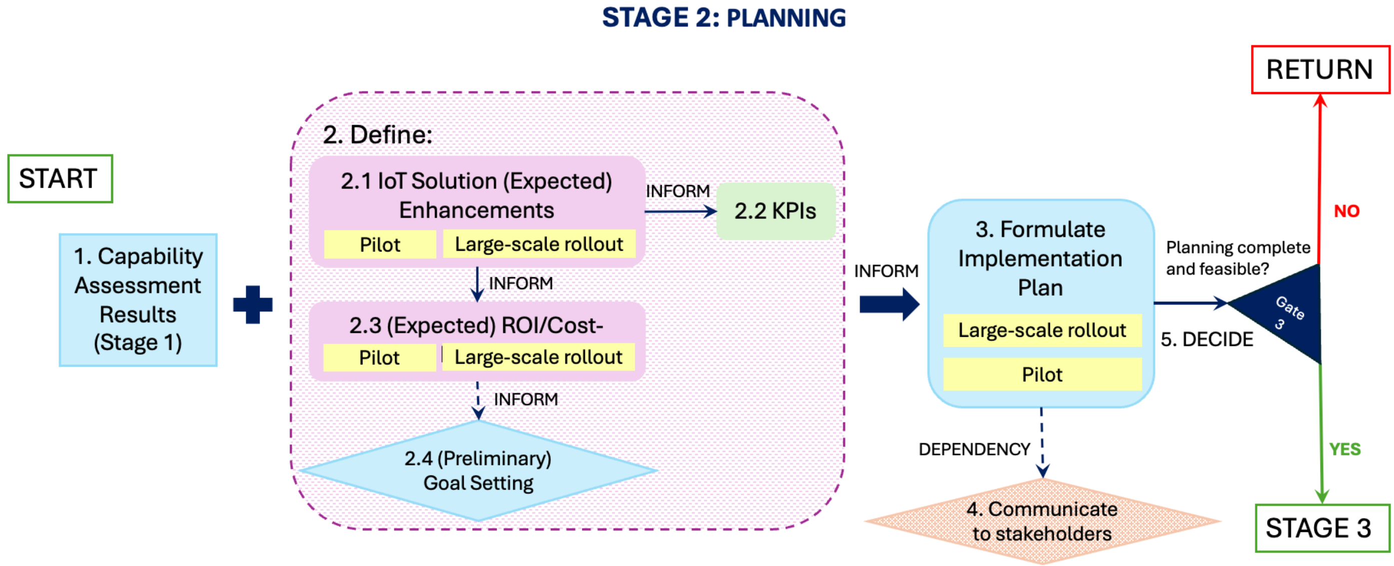

Figure 6: ITAF Prototype Stage 2 Diagram

Relationships (arrows):

- Expected returns are directly drawn from the enhancements provided by the IoT solution, as increased operational efficiency typically translates to higher long-term returns.
- From the determined expected returns, appropriate KPIs can be defined to measure progress.
- The combination of these factors, along with the capability assessment results, informs the formulation of the implementation plan.
- The implementation plan then informs the decision at Gate 3 and should be communicated to all relevant stakeholders.

Deliverable: The primary output is a thorough implementation plan for both the pilot and large-scale rollout. While adjustments for full implementation may be necessary after the pilot phase, having an initial plan in place simplifies modifications.

4.5 Framework Stage 3: Pilot Testing and Evaluation

Stage 3 is centered on executing a pilot for the IoT solution (requirement [10]), serving as the last step before large-scale implementation. This stage is particularly significant for large companies with complex operational networks, as it allows the organization to assess the solution's technological fit and minimize the implementation process impact (requirement [15]). Pilots are often considered a strong indicator of project success, as they help refine the solution, demonstrate its potential gains, and support a culture of innovation. This became prevalent in the literature review conducted in Chapter 3. However, failing to meet expectations at this stage can have serious consequences, not only for financial investments but also for the company’s willingness to accept new technology. There is a third scenario, referred to as "pilot purgatory" in Bhalekar & Eloot’s (2018) McKinsey publication, which can occur when a pilot succeeds but the project struggles to move beyond the pilot phase due to other factors such as organizational inertia or unclear next steps. The main input for this stage is the Pilot Planning defined in Stage 2.

Elements and Steps in Stage 3 (a full overview is depicted in **Figure 7**):

Step 1: Initiate Pilot Execution – Based on the pilot plan, this stage starts with the execution of the pilot project. To minimize disruption, the framework suggests selecting a single operational site in the company’s network where the IoT solution could be beneficial without heavily impacting day-to-day activities. The pilot execution may involve adjustments and fine-tuning to accommodate environmental specifics. Finally, it should run for the duration specified in the plan until quantifiable results can be collected.

Step 2: Collect Pilot Results – After the pilot run, data on the observed results of the IoT solution's enhancements is gathered, and an overview is made for easier comparison.

Step 3: Determine Observed Key Performance Indicators (KPIs) – The KPIs are also observed from the pilot results, but on two fronts: preliminary IoT benefits and the initial implementation impact (requirement [15]). This step provides insights into the solution's effectiveness and its effect on the existing processes.

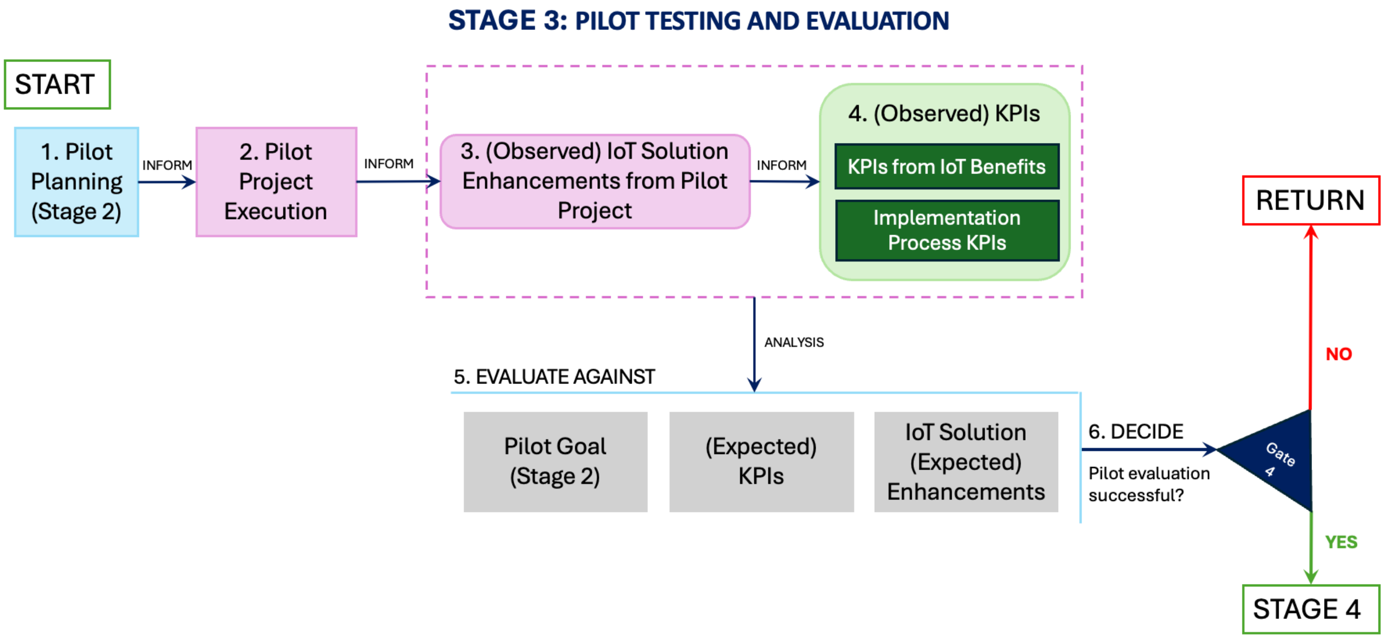

Figure 7: ITAF Prototype Stage 3 Diagram

Step 4: Evaluate Results Against Expectations – A comparison should be conducted by evaluating the observed values from the pilot against the expected values defined in the planning stage (Stage 2). At this step, the preliminary goal set in Stage 2 should also be taken into account to determine how well the pilot aligns with the anticipated project target.

Gate 4 Decision: Is the pilot evaluation against expected results successful? – This decision is informed by the pilot evaluation, which determines if it can be considered “successful” or not; the definition of "success” at this step is flexible to account for specific company requirements (requirement [14]). If the pilot demonstrates that the IoT solution meets or exceeds the established criteria for success, the project can advance to Stage 4 for full-scale implementation. However, if the pilot falls short, the company must revisit earlier stages to address the identified issues, such as reassessing capabilities in Stage 1 or reconsidering the IoT solution selected in Stage 0.

Relationships (arrows):

- The first three steps in Stage 3 are sequentially dependent: the pilot execution is carried out based on the initial plan, observed enhancements are derived from the pilot execution once it is completed, and KPIs are determined from the observed enhancements.
- The results of both observed improvements and KPIs inform the comparison evaluation.
- Evaluation results directly guide the decision-making at Gate 4.

Deliverable: The deliverable for Stage 3 is the go/no-go decision at Gate 4 itself, which determines whether the project will proceed to a full-scale rollout in the final stage. At this point, the plan has already been formulated, and this decision serves as the final critical checkpoint in the IoT adoption process.

4.6 Framework Stage 4: Large-Scale Implementation

The final stage of the Stage-Gate Process involves the large-scale implementation of the IoT solution that has successfully passed the pilot phase. This stage is focused on executing the IoT solution across the entire organization and assessing its long-term impacts. Unlike the pilot phase in Stage 3, where the focus was on testing the technology in a controlled environment, Stage 4 involves the full-scale deployment of the IoT system, continuous monitoring, and, after a set time frame, a final evaluation of its overall effectiveness. The main input for this stage is the Implementation Plan defined in Stage 2, with any necessary adjustments observed post-pilot, if applicable.

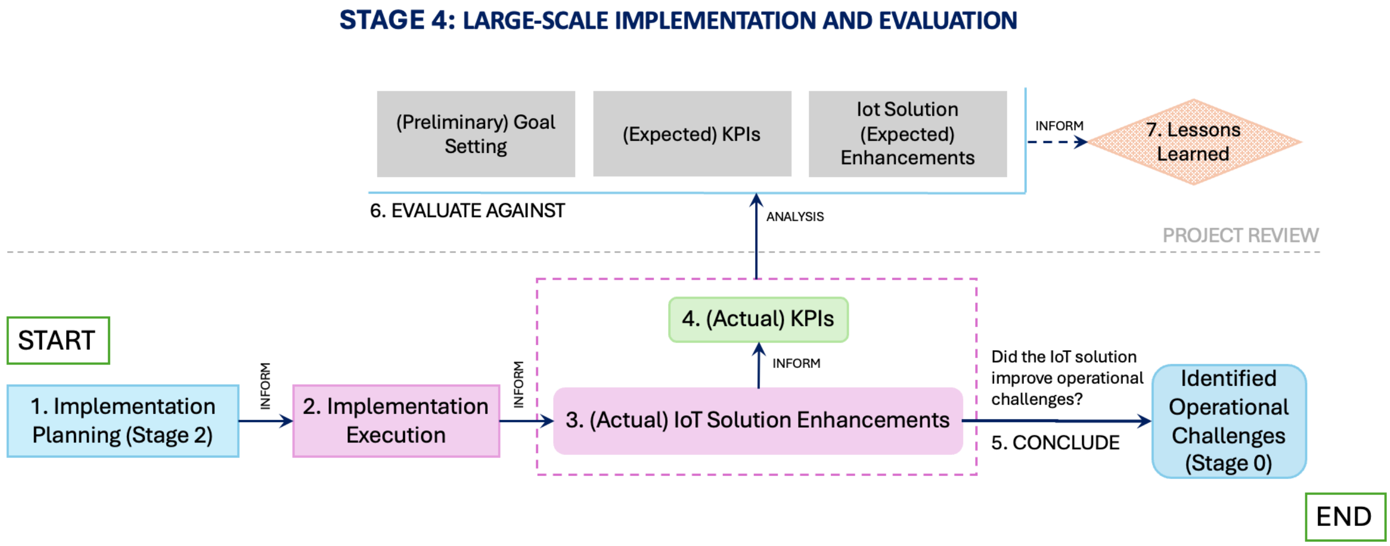

Figure 8: ITAF Prototype Stage 4 Diagram

Elements and Steps in Stage 4 (a full overview is depicted in **Figure 8**):

Step 1: Implementation Execution – The full-scale rollout is carried out based on the implementation plan, incorporating gradual scaling to mitigate risks associated with large-scale deployment (requirement [11]). This may involve tiered or regional deployment or other methods deemed suitable by the organization (requirement [14]). A predetermined timeframe should guide the deployment process, allowing time for the solution to stabilize and produce quantifiable results.

Step 2: Observe IoT Enhancements – Once the deployment is completed and the solution runs in a production environment for some time, actual improvements in operations can be observed, such as workflow optimization, efficiency, or increased equipment uptime.

Step 3: Determine KPI Values – The actual KPI values are measured post-deployment, providing a concrete basis for assessing the solution's performance.

Step 4: Evaluate Against Expectations – The actual enhancements and KPI values are compared with the expected outcomes defined in Stage 2, i.e., expected KPIs, anticipated operational improvements from IoT, and the preliminary goal. This evaluation helps to gauge the overall success of the large-scale rollout.

Step 5: Lessons Learned – The evaluation results inform lessons learned, offering insights for future IoT projects and enabling continuous improvement (requirement [12]). The lessons learned may also incorporate insights from the broader IoT adoption process, not just the large-scale deployment itself.

Step 6: Did the IoT Solution Improve Operational Challenges? – Finally, the actual IoT enhancements are reviewed to determine whether they effectively mitigated the original operational challenges identified at Stage 0 and to what extent. If the answer is yes, the IoT adoption process is deemed successful, and the project can be considered closed. Otherwise, it may be necessary to revisit certain elements of the deployment or refine the solution to achieve the desired impact. This step closes the loop in the adoption process, ensuring that the solution's deployment has delivered the intended benefits.

Relationships (arrows):

- The Implementation Plan informs the execution of the rollout.
- From the completed deployment, actual IoT enhancements are observed, which then determine the KPI values.
- Both actual enhancements and KPI values inform the evaluation against expected outcomes.
- The evaluation informs the lessons learned, which can also arise from the overall adoption process, as indicated by the dotted line.
- Lastly, the actual enhancements determine if the initial operational challenges were addressed, closing the loop on the entire adoption process.

Deliverable: The final deliverable for Stage 4 is the IoT solution fully deployed and operational across the organization, now live in the production environment. This marks the transition from technology adoption to full-scale, ongoing use, with the IoT system integrated into daily operations. The solution's live deployment provides the foundation for continuous monitoring and further improvements based on real-world performance and feedback.

4.7 Post-Launch Review and Lessons Learned

The Post-Launch Review lies outside the primary IoT adoption loop, providing a broader evaluation phase that allows for the comparison of multiple adoption projects. Its purpose is to assess the success of each initiative, establish best practices, and continuously refine the IoT adoption framework. By sharing the successful stories with relevant stakeholders, this step addresses the last requirement, i.e., requirement [5] (this marks the fulfillment of all framework requirements from the preliminary set defined in Chapter 3).

This phase begins with a systematic evaluation of projects across the six established metrics from Section 4.1: Technical Capability, Organizational Capability, Financial Capability, Technical Availability, Performance Improvement, and Implementation Process Impact. The comparison of actual outcomes with the expected results set during Stage 2 determines the project's success level – classified as successful, partially successful, or unsuccessful. Documenting lessons learned is critical, as it captures insights into effective strategies and unforeseen challenges. Key areas include technical integration, change management, and resource allocation. These findings contribute to a knowledge base that can inform and improve future projects.

The final goal is to foster continuous improvement by leveraging insights gained from multiple initiatives. Tools like the proposed radar charts can be used to visualize and compare performance across projects, helping organizations systematically identify areas for enhancement and refine their IoT adoption approach over time.

Chapter Conclusion

Chapter 4 presented a structured IoT Technology Adoption Framework (ITAF) designed to guide logistics companies through the complexities of IoT implementation, thus answering sub-question 4 of this study, *"What are the structure and design of the necessary stages in a framework for IoT Technology Adoption in 3PL companies?"*, and completing Phase 3: *Design and Development* of the DSR. This phase involved the design activity of developing an initial prototype of ITAF based on the identified requirements, creating a structured, stage-gated approach tailored for 3PL settings. The framework addresses all the key requirements in the preliminary set derived from the literature review, ensuring a systematic approach from identifying challenges to full-scale deployment. Each stage of the process integrates technical, organizational, and financial considerations, with pilot testing playing a pivotal role in minimizing risks. This approach aligns with the design objective of providing a structured pathway to navigate the unique challenges of IoT adoption in logistics, making the framework adaptable to real-world complexities. In the next chapter, expert interviews will serve as a critical evaluation tool, allowing for the identification of additional requirements and refining the framework based on real-life insights.

5

Prototype evaluation at FedEx Europe

In this chapter, the ITAF prototype is evaluated through qualitative data analysis derived from interviews with FedEx employees involved in IoT adoption. This corresponds to Phase 4: Evaluation of the Design Science Research (DSR) methodology and involves the design activity of assessing ITAF's applicability and effectiveness in a real-world context. The aim of this chapter is to answer sub-question 5 of this study: "*How does the IoT adoption framework perform when evaluated through a FedEx case study as a practical example of a 3PL company?"*. While the framework was initially developed based on literature, these interviews and past project evaluations provide essential real-world feedback to assess its applicability, identify improvements, and validate its effectiveness. By integrating insights from practitioners, the framework can be refined to better address the unique challenges of IoT adoption within 3PL companies like FedEx, ensuring that it is both practical and beneficial when applied in operational contexts.

5.1 Interview Data Analysis

The ITAF framework protoype was designed based solely on existing literature so far. However, to ensure its relevance and practical value, it is essential to incorporate user input into its development (Creswell, 2016). The aim is to tailor the framework to better serve its intended purpose – facilitating IoT adoption within 3PL companies. This validation process through interviews enables refinement of the framework, aligning it more closely with the actual challenges and needs encountered in 3PL IoT adoption. By gathering expert feedback, the framework can be tailored to address the nuanced, operational realities that literature alone may overlook (Creswell, 2016). This approach transforms ITAF from a theoretical model into a practically applicable tool that meets the specific requirements of logistics companies. Incorporating these insights supports the iterative refinement central to the Design Science Research (DSR) methodology, ensuring the framework's applicability and enhancing its value for facilitating successful IoT adoption within 3PL environments (Peffers et al., 2007).

During the interviews, as detailed in section 2.5, participants were introduced to the framework prototype, including its project evaluation metrics and objectives, to gain feedback from stakeholders involved in IoT adoption at FedEx. In addition to improvements, this also validated the framework's potential benefits for 3PL companies such as FedEx.

Objective

The objective of the interviews is to evaluate the framework's applicability in real-world scenarios by gathering user feedback and identifying potential improvements. By engaging with potential users, an informed assessment can be made about how practical and useful the framework would be when implemented in a practical context.

Qualitative Method Overview

This chapter employed an in-depth interview-based analysis of the framework with employees from FedEx Europe. Participants were fully briefed on the framework and provided consent to be recorded during the interviews. Afterward, participants signed interview transcripts to ensure accuracy. The interviews were divided into three sections. The first focused on the framework's design, including impressions, alignment with current technology adoption practices, potential improvements, and views on timelines and ownership. The second section focused on the company's experiences with adopting IoT technologies, identifying areas where the framework could be beneficial. The final section discussed the framework's potential scalability for other companies or technologies, as well as recommendations for IoT adoption within FedEx.

Qualitative Method Overview

Participants for the study were selected from European FedEx employees who have been involved or are currently involved in IoT technology adoption. The selection criteria included a range of years of experience and decision-making authority, ensuring a balanced representation – half of the participants were in management roles. Due to time constraints, four interviews were conducted and analyzed for this study.

Data Collection

The interviews were conducted individually, either in person or online. Two participants were based in the Netherlands, while the other two were from different countries within the EU. Each interview lasted approximately 1.5 hours, and data collection involved audio recordings, with transcripts prepared afterward. The demographic data was securely stored in a private, encrypted file, and a summary can be found in **Table 10** below:

Table 10: Interviews Demographic

Generic Company Role	Years of Experience	Involvement in IoT Adoption Projects	Decision-Making Power
Manager (x2) Project Engineer Senior Industrial Engineer	5-10 years (x2) 10-20 years >20 years	Currently active (x2) Previous (x2)	Decision power (x2) Advisory None

Data Management

Following the interviews, the audio recordings were securely stored in an encrypted file, and transcripts were manually prepared using the method outlined by Azevedo et al. (2018). The transcripts were anonymized by assigning identifiers such as "Interview 1." Only anonymized transcripts were shared with the research supervisors. The encrypted recordings will be stored on the TU Delft OneDrive for one year, and anonymized transcripts will be stored in the TU Delft Repository for two years.

Data Analysis

The data was analyzed according to the principles of qualitative research and systematic text condensation (Malteurd, 2012). First, I reviewed the transcripts to gain an overall understanding and identify preliminary themes that were related to the interview questions. I then defined a coding system to represent the themes and subthemes. After revisiting all the transcripts, I validated the themes and subthemes for each one. In the next step, I consolidated the themes and subthemes into a cohesive list, eliminating any repetition. Finally, I synthesized the participants' answers and their feedback as quotations.

Ethical Considerations

All participants provided written consent after receiving explanations about the study. Only those who consented were included in the research. The study did not collect or handle any sensitive data from FedEx. All interview data was anonymized, and time-stamped audio recordings were correlated to anonymized transcripts. Access to the data was restricted to the author, and participants were informed of their right to review and request changes to their own data. The TU Delft HREC and TPM faculty data steward reviewed the data management plan and informed consent form, concluding that no additional ethical review was required, as no sensitive or personal data was collected.

5.2 FedEx Europe: A Study On Technology Adoption

FedEx Corporation, a global leader in transportation and logistics, is a third-party logistics (3PL) provider known for offering a broad array of supply chain services. The company operates through various segments, including FedEx Services, FedEx Express, FedEx Ground, FedEx Freight, and FedEx Logistics, with FedEx Express being the most significant in international markets, including Europe. FedEx's ability to provide fast, reliable delivery services globally has positioned it as a key player in the logistics industry (FedEx, 2024). A notable distinction between FedEx's U.S. operations and its European counterpart is the size and scale of their respective innovation teams. FedEx U.S. has a larger, more experienced team dedicated to technological innovation, which has led to more rapid adoption of emerging technologies such as IoT and automation (Interviews 1, 2). Europe, on the other hand, has seen slower adoption rates due to fewer resources and a more fragmented market environment. However, recent efforts have been made to align the innovation processes between the two regions (Interviews 1, 2).

FedEx Acquisition of TNT in Europe:

In 2016, FedEx acquired TNT Express, significantly expanding its European footprint and capabilities (FedEx, 2016). The acquisition allowed FedEx to strengthen its position in the European logistics market by enhancing its ground and air network services. TNT's well-established European road network complemented FedEx's global air express services, positioning FedEx as a more comprehensive service provider within Europe (FedEx, 2016). This acquisition, however, also introduced a series of challenges, especially concerning the integration of TNT's legacy systems with FedEx's existing infrastructure (Interview 3). The integration of operational processes, technology systems, and corporate culture has been ongoing, influencing the pace of technology adoption in Europe.

RFID and SenseAware Technologies at FedEx:

FedEx has actively experimented with IoT technologies such as RFID and SenseAware. RFID technology was deployed previously in projects like the Blue Cages to improve asset tracking, but the project was eventually abandoned due to technical limitations and changing operational priorities (Interview 1,2,3). Recently, SenseAware has been a more successful IoT implementation, primarily used for high-priority and sensitive shipments, such as medical supplies. This technology allows real-time tracking of shipment conditions, such as temperature and location, significantly enhancing the customer experience (Interview 1, 2). These projects demonstrate FedEx's commitment to IoT but also highlight the complexities of large-scale rollouts and the importance of structured frameworks like ITAF in navigating these challenges.

Relevance of FedEx as a Case Study for Framework Evaluation:

FedEx serves as an ideal case study for evaluating the proposed IoT Technology Adoption Framework (ITAF) due to its ongoing efforts to integrate innovative technologies like IoT into its complex logistics operations. As a large 3PL provider, FedEx deals with the common challenges of large-scale technology adoption, making it a fitting example of how ITAF can be applied to streamline such processes. The similarities between the existing FedEx adoption process and the ITAF stages make it particularly relevant. While FedEx follows a step-by-step process for its technology rollouts, this process is seemingly less structured than ITAF, leading to delays, particularly at the pilot-to-implementation stage (ITAF Gate 4) (Interviews 1, 2,3,4). Evaluating the effectiveness of ITAF in addressing these bottlenecks, especially regarding resource allocation and cross-functional coordination, can provide valuable insights into how 3PL companies like FedEx can optimize their technology adoption timelines and processes.

In conclusion, FedEx offers an adequate and relevant case study for the evaluation of ITAF, providing key insights into both the successes and obstacles associated with IoT technology adoption in a large 3PL company.

5.3 Qualitative Analysis Results

5.3.1 Overview Of Themes And Subthemes

Six main themes were identified from the data analysis (see **Appendix C**): current 3PL challenges (Theme 1), framework evaluation insights (Theme 2), IoT adoption timelines (Theme 3), IoT project ownership (Theme 4), framework improvements (Theme 5), and framework benefits for the company (Theme 6). During the analysis, only one notable difference in the answers provided by various participants was observed. As such, the themes are not grouped based on participants' roles or expertise, but the interview identifiers are cited to provide context to specific quotations. An overview of the identified themes and subthemes is presented in **Table 11**. **Table 12** outlines the relationship between the identified subthemes, the questions from the interview guide, and this study's research subquestions (SQs). The results in the following sections use the interview identifiers and question numbers as references for clarity; for example, “Interview 1, Q1” refers to the answer provided in Interview 1 for question 1 of the interview guide.

Table 11: Interview Analysis Themes and Subthemes

THEMES
Theme 1: Current 3PL Challenges Subthemes: 1.1 IoT is a topic of interest, but progress in adoption is slow. 1.2 Technical challenges focus around integration with legacy systems, evolving technology and setting realistics goals. 1.3 Organizational challenges focus on resistance to change, regional differences, and experience. 1.4 Financial challenges include budget limitations, price fluctuation, and the importance of ROI for leadership. 1.5 Majority of projects are stuck after pilot completion (Gate 4).
Theme 2: Framework Evaluation Subthemes: 2.1 ITAF is comprehensive and structured, which is preferred.

2.2 ITAF is adaptable, making it applicable for any 3PL companies, for various technologies, and various regions.

2.3 Project evaluation metrics are complete.

2.4 Financial considerations should indeed be included as a priority focus.

2.5 ITAF would benefit FedEx, as it is similar to the company's existing processes but offers a more rigorous and structured guideline/framework.

Theme 3: IoT Adoption Timelines

Subthemes:

3.1 Overall, the adoption process should take approximately one year (maximum 1.5 years).

3.2 Variation based on project complexity should be expected.

3.3 Adoption process at FedEx is slower: delays at Stages 2 and 3.

3.4 Maintaining the momentum is vital, because longer timelines reduce the chances of success.

3.5 Multiple reviews should be included during the adoption process, with a post-launch review after complete implementation.

=> **Notable difference:** Interview 3 suggested a post-launch review should be conducted at 80% of the full-scale implementation.

Theme 4: IoT Project Ownership

Subthemes:

4.1 Innovations/R&D teams lead the initial stages, i.e., Stages 0-3.

4.2 The implementation team leads the full-scale implementation, i.e., Stage 4.

4.3 Cross-functional involvement at each stage is crucial, but also causes delays.

4.4 Company leadership is involved mainly at Gates 2 and 4.

4.5 Other crucial stakeholders include new IoT users, customers and vendors.

Theme 5: Framework Improvements

Subthemes:

5.1 Include process timelines and ownership at each stage.

5.2 Include pilot preparation and installation separately from pilot planning and execution.

5.3 Consider ROI for leadership during post-launch review.

5.4 Consider vendors as key stakeholders at Stages 0, 2, 3, 4.

5.5 Account for other negative factors: capabilities (from Stage 1) can change throughout the adoption process; external factors.

5.6 Make it visible in the framework diagram that a completed adoption process provides feedback/lessons learned for future projects.

Theme 6: Framework Benefits for Company

Subthemes:

6.1 A structured framework could enable the company to follow the stages more rigorously.

6.2 Full financial assessment is more useful if conducted early (Stage 1).

6.3 Realistic execution timelines should be defined early to reduce the risk of delays (Stage 2).

6.4 ROI should not be the only benefit of interest for leadership.

6.5 The standardized approach enables collaboration, which increases chances of success.

Table 12: Interview Questions

INTERVIEW PART AND QUESTIONS	SQs	SUBTHEMES
PART 1: IOT ADOPTION ANALYSIS FRAMEWORK		
Q1. I will start by introducing ITAF. [...] Any questions or clarifications required so far?	-	-
Q2. What are your initial thoughts and impressions of the framework?	SQ5	2.1, 2.2, 2.3, 2.5
Q3. How does this framework compare to the current process of IoT technology adoption at FedEx?	SQ5	2.1, 2.2, 2.5, 5.2
Q4. From your experience, how long should each stage take on average?	SQ4	3.1, 3.2, 3.4, 5.1, 5.2
Q5. How about at FedEx in particular? How long does that take and how does it compare with the general scenario?	SQ5	1.5, 3.3
Q6. From your experience, who would have decision ownership over each of the Gates in the framework?	SQ4	4.1, 4.2, 4.3, 5.1, 5.4
Q7. How involved is the leadership in the decision-making process at each of those gates?	SQ4	4.4, 5.3, 6.2, 6.4
Q8. Would you then say that the large number of people and teams involved in the decision-making process may be leading to project delays?	SQ2	4.3, 5.4. 6.5
Q9. What about the post-launch review? When does that take place, and who is the owner of it?	SQ5	4.5, 5.3, 6.4
Q10. From your experience, what technology adoption challenges is FedEx currently facing (technological, organizational, financial)?	SQ5	1.2, 1.3, 1.4, 5.2, 5.5
Q11. Would you say the financial aspect is indeed a big factor at play for FedEx or other similar 3PL companies when it comes to technology adoption?	SQ5	1.4, 2.4, 5.4, 5.5, 6.4
Q12. One issue identified from the research is that KPIs are hard to define in a more general framework, seeing as they are quite technology-specific. Do you agree with this, and why?	SQ5	2.3, 6.4
Q13. What about the ITAF project evaluation metrics? Would you suggest adding or removing anything?	SQ5	2.3, 5.3, 5.5, 6.4

Q14. Finally, do you have anything else to add for this section on the framework before we move on?	SQ5	5.6
PART 2: FEDEX IOT TECHNOLOGY ADOPTION		
Q15. How would you describe FedEx's efforts with IoT technology adoption over the past several years? Have they been involved in many projects?	SQ5	1.1, 1.5, 5.5, 6.1, 6.3
Q16. How many of these projects have been fully completed?	SQ5	1.1, 1.5, 6.2, 6.3, 6.4
Q17. Regarding the projects that were not completed, where would you say the majority got stuck? At which stage (out of the 5)? And why?	SQ5	1.5, 6.1, 6.2, 6.4
Q18. Regarding the project concerning RFID on Blue Cages, is this the first IoT-related project that FedEx (at the time TNT) has been involved in?	SQ5	1.1
Q19. Can you describe that project in a short summary?	SQ5	-
Q20. What would you say went wrong there? And what were the lessons learned?	SQ5	1.2, 1.5, 5.5
Q21. Now, alternatively, if we look at the latest IoT project FedEx has been publicly involved in, SenseAware, how would you describe this project?	SQ5	-
Q22. What would you say the difference was between this project and the others that did not make it to completeness, which ultimately led to its success?	SQ5	1.3, 1.4, 6.4
Q23. Would you say the innovation adoption approach in the FedEx US is in line with the one in FedEx Europe?	SQ5	2.2, 5.6, 6.5
Q24. Therefore, would you consider that ITAF would also be applicable to the US approach (you can take the example of SenseAware)?	SQ5	2.2, 2.5, 6.1, 6.5
Q25. Lastly, I want to look at the potential of this project (SenseAware) to be implemented here in Europe. Based on the framework and the current FedEx challenges, do you think this is feasible?	SQ5	1.2, 1.3, 1.4
Q26. What are some key considerations and/or blockers that you think could impact the introduction of SenseAware in FedEx Europe?	SQ5	1.2, 1.3, 1.4, 6.1, 6.5
PART 3: RECOMMENDATIONS		
Q27. To conclude, do you think FedEx would benefit from following ITAF for its IoT technology adoption?	SQ5	2.1, 2.2, 2.5, 6.1, 6.5
Q28. What recommendations would you give for FedEx to improve its success with IoT technology adoption?	SQ5	6.1, 6.3, 6.5
Q29. And finally, do you think ITAF has the potential to be extended for a broader use (for different companies or different types of technology)?	SQ5	2.1, 2.2, 6.1, 6.5

5.3.2 FedEx Current IoT Technology Adoption Landscape

At FedEx, IoT technology adoption follows a process similar to ITAF, though not as structured. While there have been successful pilots, many projects face delays due to external factors, organizational resistance (subtheme 1.3), and difficulties integrating new technologies with legacy systems (subtheme 1.2). Despite strong interest, progress remains slow, especially in completing large-scale rollouts and overcoming internal resistance (subtheme 1.1).

> "*I would say there have been tentatives, and the will is there to implement IoT. [...] the plan was that as of 2020, they would implement more systems with IoT. And now we are in 2024, [...] And so far, we don't have any IoT projects that are rolled out as an IoT project in Europe*" – Interview 4, Q15

The technology adoption process at FedEx generally involves several stages as well, from idea generation to full-scale implementation. However, many IoT projects have become stuck after the pilot phase, particularly at Gate 4 of ITAF, where projects transition from pilot programs to large-scale deployments (subtheme 1.5). This bottleneck often results from resource constraints, unclear decision-making processes, and challenges in aligning cross-functional teams. Additionally, technical challenges related to integrating IoT with existing legacy systems and infrastructure have hindered the pace of adoption (subtheme 1.2).

> *"...they actually were substantial projects [...] they were stuck before they really got to large-scale implementation [...] post-pilot, prior to large implementation."* – Interview 3, Q17

Organizational challenges also remain an issue at FedEx, particularly around regional differences and resistance to change (subtheme 1.3). Employees who have long been accustomed to traditional methods often struggle with adapting to new technologies, necessitating strong change management strategies. Additionally, FedEx's global reach exacerbates these challenges, with regional teams often operating with varying degrees of autonomy. Balancing the need for centralized decision-making with the flexibility required by regional teams has been a critical aspect of the adoption process (subtheme 1.3).

> *"The biggest challenge FedEx is facing is the size of FedEx."* – Interview 2, Q10

> *"...you can have a really top-of-the-art technology, but if the people using it are not doing so correctly, it's useless."* – Interview 4, Q10

Financial challenges also play a crucial role in the IoT adoption landscape at FedEx. Budget limitations, price fluctuations, and the cost of implementing cutting-edge technologies have delayed several projects (subtheme 1.4). For instance, during the post-pandemic period, significant price increases in semiconductor-based products disrupted the deployment timelines of new technology projects. Additionally, projects often struggle to demonstrate a clear, early return on investment (ROI), which can lead to their abandonment before full-scale implementation (subtheme 1.4).

Historically, FedEx has engaged in several IoT-related projects (subtheme 1.1), the earliest dating back to TNT before the merger and involving the use of RFID tags on Blue Cages to track them across the network. While this project initially provided valuable insights and returns, it ultimately encountered challenges related to solution obsolescence due to changes in the operational processes. Despite its initial success, the project was abandoned as the company's needs and operational focus evolved after the TNT/FedEx merger.

5.3.3 Evaluation of the Proposed Framework

The ITAF prototype was generally well-received by participants, who found it comprehensive and structured (subtheme 2.1). Interviewees agreed that the structured nature of ITAF, with clear steps from idea generation through to implementation, would benefit companies like FedEx by reducing uncertainties and providing clear guidance throughout the technology adoption process (subtheme 6.1). The framework's adaptability was also highlighted as a key strength, allowing it to be applied across various regions, industries, and for different technologies, thus making it versatile for 3PL companies and beyond (subtheme 2.2).

> *"I believe standardization through adopting a general model and bringing clarity to everybody, including stakeholders, delivers only benefits."* – Interview 2, Q27

> *"I think that the framework you are putting in place, you know, it's general. It should be applicable not only to FedEx but to any company."* – Interview 4, Q24

> *"...you focused on the IoT section only, but I can assure you that it has applicability in, well, I won't say all industries, but all the industries that I have experience [...] And I wish more small to medium-sized companies would actually do their structuring, their project structuring based on your stage gate process logic. Because for sure, they will save them a lot of time."* – Interview 1, Q27

The project evaluation metrics within the framework were seen as complete, covering all necessary dimensions such as technical availability, organizational readiness, implementation impact, and financial considerations (subtheme 2.3). This was viewed as critical for decision-making, as FedEx often needs to balance multiple factors when assessing whether to move forward with a project. The inclusion of financial considerations, particularly the emphasis on returns, was also seen as a priority, aligning with FedEx's need to ensure that technology investments are financially viable (subtheme 2.4).

> *"And I can also tell you that in all the companies I've been before, including FedEx, you need a value for investment. So, you need to justify that. Every single company has a priority of also being profitable. No matter how much they are focused on technology, you also need to focus on being profitable. Because if you're not profitable, then you can't afford to invest in technology…"* – Interview 1, Q11

Furthermore, all interviewees expressed the belief that ITAF would provide substantial benefits to FedEx by helping the company streamline its IoT adoption processes (subtheme 2.5). Given that the innovation adoption processes in Europe and the U.S. are becoming increasingly aligned, the framework has the potential to be scaled up across all of FedEx, supporting a unified "FedEx as one" approach. Specifically, stages 0 to 2 could be centralized across all FedEx regions, focusing on global alignment, while for stages 3 and 4, the regional teams could take over (subtheme 6.5).

5.3.4 IoT Adoption Process Timelines and Ownership

Two limitations already identified in Chapter 3 concerned the lack of clear literature insights into adoption timelines and ownership. The interviews highlighted several key factors regarding these aspects of IoT adoption processes at FedEx. According to the experts, the overall adoption process should ideally take one year in order for the technology to remain relevant post-implementation (an acceptable maximum of 1.5 years) (subtheme 3.1), with variations depending on project complexity (subtheme 3.2). This is related to the fast pace of technological advancements, which indirectly raises the requirement for shorter integration timelines. While smaller projects may fit within the one-year timeframe, more complex implementations could extend beyond this, with delays frequently occurring in stages 2 and 3 of ITAF due to external factors such as vendor readiness or software development challenges.

> *"I believe that in general, end-to-end process should be somewhere between one year and 1.5 years…"* – Interview 1, Q4

> *"…those iterations shouldn't take more than a quarter, max two, because every time you see people change, teams change, situations change on the floor…"* - Interview 3, Q4

Despite these goals, the IoT adoption process at FedEx has generally been slower, with many projects experiencing delays and prolonged timelines, particularly during the planning and pilot stages (subtheme 3.3). Maintaining momentum is vital to preventing extended project durations, as longer timelines can reduce project success rates due to organizational (team) changes, price fluctuations, or evolving business needs (subtheme 3.4). These delays often cause projects to enter "pilot purgatory" at Gate 4.

> *"Stage three […] I don't think it should take more than three months. Because if it takes more than three months, you are losing the momentum. […] you need to restart from stage one."* – Interview 2, Q4

> *"But if two years pass between gate four and stage four, people will forget that you have piloted something sometime a while ago."* – Interview 1, Q17

Regarding ownership of the IoT adoption process, the Innovations or R&D teams should typically lead the initial stages, from idea generation to pilot planning and execution (subtheme 4.1). However, cross-functional involvement across departments is crucial, as various stakeholders – such as operations, finance, vendors, and the legal department – contribute at various stages throughout the process as well. Amongst these, the most relevant stakeholders throughout the adoption project, aside from the owners at each stage, are the end-users (operations), company customers, and technology partners (vendors)(subtheme 4.5). This cross-functional collaboration, while beneficial for incorporating specialized knowledge, has also been cited as a cause of delays due to misalignments and conflicting priorities between teams (subtheme 4.3). Once projects reach full-scale rollout (ITAF Stage 4), R&D hands over to the implementation team, ensuring the rollout aligns with the pilot learnings and that the necessary resources are available for scaling up (subtheme 4.2).

> *"... for us, the customer's needs come first."* – Interview 1, Q21

> *"... having an engaged and supportive end-user, I believe it's probably 50% of the success of your project. Without it, it's almost mission impossible."* – Interview 1, Q26

Additionally, management involvement is particularly relevant at ITAF Gates 2 and 4, where decisions regarding budget approval, ROI assessments, and project continuation are made (subtheme 4.4). Post-launch reviews also play an important role in ensuring project success, with several preliminary reviews recommended throughout the implementation to gather feedback and integrate lessons learned (subtheme 3.5). The post-launch review ownership lies between the Innovations/R&D team, the implementation team, the end-users, and leadership.

5.3.5 Practical benefits from ITAF for FedEx

Several potential benefits from the framework have been observed for FedEx. A significant advantage of the framework is its comprehensive, structured approach for each stage, which could enable FedEx to follow its IoT adoption steps more rigorously and efficiently (subtheme 6.1). Interviewees indicated that ITAF's formalized structure would reduce the risk of projects deviating from their timelines and objectives, helping to maintain momentum and focus throughout the adoption process.

> *"I would like to improve our framework based on your framework"* - Interview 1, Q27

Another key benefit of ITAF is its emphasis on early financial assessment (subtheme 6.2). Integrating financial evaluations in Stage 1, for both pilot and full rollout, ensures that FedEx can make informed decisions about resource allocation and avoid engaging in projects without a clear understanding of potential costs and returns. While early predictions can be hard to evaluate, this approach to financial assessment allows leadership to better align their investments with strategic goals, avoiding the common pitfall of overextending resources across too many initiatives simultaneously, which ultimately may not bring any benefits if left unfinished.

Additionally, ITAF emphasizes the importance of establishing realistic execution timelines during Stage 2 to prevent delays in the project rollout (subtheme 6.3). By defining feasible timelines early, FedEx can mitigate the risks of extended adoption cycles, which can negatively impact project success and erode stakeholder confidence. Interviewees emphasized the value of defining clear, achievable milestones, particularly during the pilot and large-scale implementation phases, to ensure project success.

> *"The trust is gone if you fail too often. Once is usually already too often."* – Interview 3, Q11

> *"I would say that's one of the biggest challenges there, and for technical capabilities, it's coming back a bit of what I discussed before when we were discussing the framework, is that you need to make sure that your goals have been set realistically..."* – Interview 4, Q10

While financial ROI remains important, the framework also encourages FedEx to consider other metrics of project success. Leadership should broaden their focus beyond just immediately tangible financial returns to include qualitative benefits such as customer satisfaction and operational efficiency (subtheme 6.4). For instance, ITAF encourages FedEx to explore how IoT adoption can enhance service delivery, improve operational workflows, and create new opportunities for customer engagement, as demonstrated in the success of projects like SenseAware.

Finally, ITAF promotes a standardized approach across different regions, enhancing collaboration between teams and increasing the likelihood of project success (subtheme 6.5). As the innovation adoption processes in Europe and the U.S. align, the framework holds the potential for scaling up across all of FedEx, fostering a unified "FedEx as one" strategy. In particular, Stages 0 to 2 could be centralized across all regions, ensuring global alignment in challenge identification, capability assessment, and planning. This approach helps to align innovation efforts globally, allowing FedEx to operate more cohesively, streamline processes, and avoid duplicated efforts. From Stages 3 to 4, regional teams could take over, running pilots and scaling implementations in parallel, tailored to the specific needs of each region. This would allow FedEx to benefit from global synergies while maintaining the flexibility to address regional variations and challenges, ultimately speeding up technology adoption and improving overall project outcomes.

> *"...the same framework can be applicable on a different scale. The same framework is valid for FedEx as one."* – Interview 2, Q24

5.3.6 Improvements for the Proposed Framework

The interviewees provided several suggestions for improving the framework prototype, particularly in areas related to vendors as vital stakeholders and the inclusion of additional considerations that can affect IoT adoption. One addition that was made possible through the interview analysis refers to the adoption timelines and ownership at each stage of the framework (subtheme 5.1). The high relevance of these aspects stemmed from the recurring delays in the IoT adoption process at FedEx and all the subsequent complexities this adds to the overall process. In order to accurately represent the desired timelines for each stage, the interview analysis insights and aggregate results are presented in **Table 13**, with stage timelines translated into weeks.

Table 13: ITAF Timelines from the Interviews

TIMELINE	INTV 1	INTV 2	INTV 3	INTV 4	RESULTS
STAGE 0	2-4 weeks	Continuous	Continuous	<8 weeks	Continuous (2-4 weeks after solution identification)
STAGE 1	4-8 weeks	2 weeks	<12 weeks	4-8 weeks	4-8 weeks (2 weeks once the process is streamlined)
STAGE 2	16-24 weeks	2-4 weeks (no dev)	12-24 weeks	8-12 weeks	12-24 weeks (2-5 weeks without additional solution development)
STAGE 3	20-28 weeks	12 weeks	12 weeks	10-14 weeks	2-4 weeks (installation) Approx. 12 weeks (testing)
STAGE 4	Variable	Variable	12-24 weeks	<24 weeks	Max. 24 weeks
OVERALL	1-1.5 years	-	1-1.5 years	1 year	1-1.5 years (without Stage 0)

One major improvement would be to add the pilot preparation and installation steps between pilot planning and execution (subtheme 5.2). Seeing as the solution customization and fine-tuning take place at this step, the distinction would allow for better planning of timelines and resource allocation before moving into the actual pilot. The solution integration requirements can vary for new technologies, so a margin of error in the timeline should be considered during this step. This separation could prevent issues such as unanticipated resource shortages, both financial and personnel, which have previously been a key bottleneck, causing projects to stall.

> *"The installation itself, I believe it might take up to a month, and then the testing phase…"* – Interview 1, Q4

Interviewees also emphasized the importance of considering return on investment (ROI) during the post-launch review (subtheme 5.3). While expected ROI is typically evaluated during the initial stages of a project, it was noted that post-launch assessments should include an in-depth ROI analysis to ensure that the technology is delivering the expected financial benefits. However, it was also suggested that ROI should not be the only benefit considered (subtheme 6.4), as focusing solely on financial returns could overshadow other valuable metrics, such as operational efficiency and customer satisfaction. Therefore, a more general cost-benefit analysis is preferred.

> *"But I think the most important is the return on investment, which everybody is looking at."* – Interview 2, Q12

> *"I'm thinking about the AGV, the AMRs […] The gain for robotics is to have a productivity which is 24-7 and you don't have any fluctuation in your productivity. But in terms of performance per hour, it can happen quite often that, for AGV, for example, that the [manual driving] forklift will maybe do a better performance."* – Interview 4, Q11

Additionally, vendors should be regarded as key stakeholders throughout the entire adoption process, with the exception of internal capability assessment (Stage 1) (subtheme 5.4). This would help ensure that the technology being adopted is fully supported by its vendors, preventing technical challenges or delays due to vendor-related issues. Long-term relationships with vendors can also present benefits for the adoption process, starting from Stage 0, where vendors themselves could propose new technology solutions.

Interviewees also stressed the importance of accounting for external factors and potential changes in capabilities that could arise throughout the adoption process (subtheme 5.5). Capabilities assessed at Stage 1 may evolve over time, suggesting that the framework should include provisions for re-evaluating capabilities at later stages. Additionally, external factors such as market shifts, supply chain disruptions, cyberattacks, or various types of crises can also impact a project's success and internal capabilities. However, including them in the framework could prove challenging due to their unpredictable nature.

> *"…you can have a vendor that comes in the middle of the project and says, 'well, we are struggling with finances', or 'the cost now has increased so much that we need additional payment'."* – Interview 1, Q17

> *"…a lot of times it's the external things which impact your success, but it's not something you really can determine upfront. Takeovers of a company, halfway [through the] project, cyberattacks, and the pandemic…"* – Interview 3, Q13.

Lastly, the framework diagram should make it visible that a completed IoT adoption process provides feedback and lessons learned for future projects (subtheme 5.6). This feedback loop would ensure that best practices gained from completed projects are documented and used to inform subsequent adoption efforts, facilitating continuous improvement.

> *"So, we take that feedback from those teams that are doing the rollout, and then for the next pilot that we will be doing, we embed that feedback."* – Interview 1, Q4

> *"…just ensure that continuation of the loop, but for other projects, for the next project."* - Interview 1, Q14

5.4 Retrospective Evaluation of ITAF

In addition to the initial evaluation of the IoT Technology Adoption Framework (ITAF) conducted through interviews, a retrospective assessment was carried out using a sample of past IoT projects at FedEx (see **Appendix D**). The primary objective of this retrospective evaluation was twofold:

1. To assess the applicability of the ITAF in real-world IoT adoption scenarios and determine its effectiveness in guiding projects through the various stages of their lifecycle.

2. To identify areas for potential improvement within the ITAF prototype, with a particular focus on refining the framework based on insights gained from the analysis of previous projects.

Due to the limitations of this thesis research study, it was not feasible to apply the ITAF to an ongoing project in real-time. Instead, the retrospective evaluation adopted an analytical approach, applying the ITAF's Stage-Gate process and project evaluation metrics to a review of existing IoT initiatives at FedEx. This allowed for a comprehensive understanding of how well the framework aligns with real-world project dynamics and provided valuable feedback for enhancing the ITAF's effectiveness in future implementations.

By reviewing completed projects through the proposed ITAF process, the study gained insight into how the framework could be adapted to better address challenges encountered in practice. These findings contribute to the ongoing refinement of the framework, ensuring it remains both practical and robust in guiding IoT adoption across logistics operations.

5.4.1 Key Lessons Learned (LL1-LL6) and Framework Improvements (IF1-IF3)

The retrospective evaluation of previous IoT projects at FedEx revealed several key lessons learned (LL) for the company and suggested improvements to the ITAF (IF). These insights closely align with the themes and subthemes identified in the initial interview-based evaluation:

Lessons learned for 3PLs based on ITAF:

LL1: Apply a more thorough approach to assessing capabilities and formulating a plan (subthemes 6.1 and 6.3).

The retrospective analysis highlighted that inadequate planning or overestimation of capabilities often led to project failures in later stages. This underscores the importance of ITAF's early-stage capability assessments. It reinforces the evaluation subtheme, emphasizing the need for rigorous evaluations at every stage of the adoption process to mitigate risks effectively.

LL2: Set clear roles and responsibilities from the start (subtheme 4.4).

Many projects faced setbacks due to unclear roles and ownership, particularly after the pilot phase. This illustrates the need for well-defined leadership and decision-making responsibilities, aligning with the initial evaluation's identification of leadership challenges and the importance of structured ownership throughout the process.

LL3: Allocate appropriate resources for each stage (subtheme 1.5 and 6.1).

Delays and bottlenecks often occurred due to inadequate resource allocation, especially following the pilot testing. This aligns with subtheme 1.5, which highlights an existing issue in 3PL with projects' adoption progress being halted after pilot testing completion (Gate 4 in ITAF). The insight also aligns with subtheme 6.1, where a structured framework that emphasizes early and comprehensive planning is recommended.

LL4: Do not invest if organizational capabilities are insufficient (subthemes 1.3 and 4.5).

The evaluation showed that many projects were abandoned due to insufficient organizational readiness. This reinforces the need for strong change management strategies and comprehensive, early organizational capability assessments.

LL5: Use successful projects as benchmarks for future best practices (subthemes 4.5 and 5.6).

The success of certain IoT initiatives demonstrated the value of learning from past projects and using them as benchmarks for future implementations. This finding ties directly to the interview subthemes, which highlight the importance of continuous improvement based on previous outcomes.

LL6: Financial capabilities should be evaluated and planned more realistically (subthemes 1.4 and 6.2).

The high upfront costs of IoT adoption were identified as a critical factor in project delays and failures. Companies show interest in IoT but are risk-averse toward the typically high initial investments such technologies entail. The need for more realistic financial planning echoes the interview analysis finding that many IoT projects at FedEx stalled due to budget limitations and an overemphasis on ROI.

Framework Prototype Improvements:

IF1: Re-assess capabilities after pilot testing and review the large-scale implementation plan (subthemes 5.2 and 5.5).

Projects often encountered issues at Gate 4, mainly due to overestimations during the initial capability assessment. Reassessing capabilities after pilot testing and reviewing the large-scale implementation plan will ensure that projects are better prepared to proceed, addressing the recurring bottlenecks at this stage.

IF2: Establish clear guidelines for ownership at each stage (subtheme 5.1).

The lack of clear ownership at various stages caused delays, particularly during the transition from pilot to large-scale implementation. Establishing explicit guidelines for ownership aligns with the interview analysis findings on the need for structured cross-functional involvement and leadership throughout the adoption process.

IF3: Clearly indicate in the diagram that insights from past projects should inform future ones (subtheme 5.6).

Incorporating lessons from past projects into future initiatives is essential for continuous improvement. Formalizing feedback loops from one ITAF process to the next ensures that both successes and failures guide future IoT adoptions.

5.4.2 General Findings from the Retrospective Evaluation

The retrospective evaluation of FedEx's IoT projects offers several overarching insights as well, that complement and reinforce the themes and subthemes identified in the earlier evaluation of ITAF:

ITAF's Early-Stage Strengths: Capability Assessments

The retrospective analysis confirmed that ITAF excels at identifying technical and organizational weaknesses early in the adoption process. Projects that were abandoned during Stage 1 (Capability Assessment) demonstrated that the framework effectively prevented significant resource investment in projects unlikely to succeed. This insight ties directly to subthemes 2.1 and 2.5, which emphasized the value of ITAF in helping companies in their adoption process due to its structured approach, thereby minimizing risk and avoiding costly mistakes.

Challenges with Organizational Capability and Resource Allocation

Both the retrospective and interview-based evaluations consistently highlighted struggles with organizational capability and resource allocation. Many IoT projects stalled or failed due to insufficient organizational readiness and a lack of resource commitment, particularly after the pilot phase. This connects to subthemes 1.3 (Organizational Challenges) and 1.4 (Financial Challenges), where the evaluations identified the need for improved change management, employee training, and strategic resource planning as crucial for successful IoT adoption.

The Critical Role of Gate 4 and Pilot Phase Planning

The pilot phase (Stage 3) and the transition into implementation (Gate 4) emerged as particularly high-risk points in the IoT adoption process. Both evaluations highlighted that numerous projects failed to advance beyond this stage, primarily due to inadequate planning and inaccurate capability assessments. This finding underscores the importance of

IF1, which aims to address such risks. The challenges encountered at Gate 4 were a key insight in subtheme 1.5 (Gate 4 Challenges), further reinforcing the necessity of detailed planning and realistic capability assessments for large-scale implementation after the pilot phase.

Learning from Success/Failures: Benchmarking and Continuous Improvement

The evaluations emphasized the significance of learning from past IoT projects, both successful and unsuccessful, and using them as benchmarks for future initiatives. Whether a project succeeded or failed, each outcome provides valuable insights into what worked and what did not. The success of certain projects highlighted the value of standardized processes, while the failures underscored the importance of identifying gaps and addressing them in future efforts. Implementing feedback loops ensures continuous improvement and prevents recurring mistakes. This insight aligns with subtheme 5.6 (Projects Lessons Learned) and reinforces the need for IF3 within the ITAF framework, ensuring that lessons learned, whether from success or failure, are applied to enhance the likelihood of success in future IoT projects.

Chapter Conclusion

The interviews and past project evaluations conducted with FedEx employees revealed valuable insights into the practical application of the ITAF framework. This design evaluation activity aimed to assess ITAF's applicability and effectiveness in a real-world setting. The findings answered sub-question 5 of this study, *"How does the IoT adoption framework perform when evaluated through a FedEx case study as a practical example of a 3PL company?",* and marked the completion of Phase 4: Evaluation. Overall, the framework was seen as structured, adaptable, and beneficial for streamlining IoT adoption. Feedback from the interviews highlighted areas for improvement, such as clearer timelines, stakeholder ownership, and pilot planning. Furthermore, the evaluation confirmed that the ITAF framework is well-suited for 3PL companies like FedEx, with the potential to enhance both efficiency and strategic alignment in IoT technology adoption. The next step is to formalize the new set of requirements and further refine the framework based on these insights.

6 Updated IoT Technology Adoption Framework

This chapter focuses on answering the last sub-question of this study, sub-question 6: *"How can the IoT adoption framework be improved based on the evaluation insights to ensure it meets the operational needs of 3PL companies?"*. Following the DSR methodology outlined in Chapter 2, this stage corresponds to Phase 5: Revision, where the design activity involves refining and updating the initial framework based on expert feedback and the analysis conducted in Chapter 5. By incorporating insights from industry professionals and reflecting on potential improvements, this chapter aims to ensure that the framework is practical, comprehensive, and aligned with real-world applications. This process is vital for ensuring that the framework not only meets theoretical requirements but also effectively addresses the challenges faced by 3PL companies in adopting IoT technologies. This chapter will start with creating a new set of requirements that resulted from the qualitative interview analysis and will conclude with an overview of the improved version of the framework.

6.1 Evaluation Primary Findings

The new resulting ITAF requirements from the interview analysis, particularly section 5.3.5, are shown in **Table 14**:

Table 14: New Set of Requirements from Evaluation

DESIGN PRINCIPLES	REQUIREMENTS	SUBTHEME
Design Principle for Framework Development	[21] **The framework must define process timelines and ownership for each stage.** This requirement ensures that roles and responsibilities are clearly outlined, preventing delays caused by ambiguous ownership.	Subtheme 5.1 IF2
Design Principle for IoT Adoption in Logistics	[22] **The framework must separate pilot preparation and installation from pilot planning and execution.** This requirement ensures that the necessary groundwork is completed before moving into pilot execution, increasing the likelihood of a successful pilot.	Subtheme 5.2
	[23] **The framework could include vendors as key stakeholders at Stages 0, 2, 3, and 4.** This requirement ensures that vendor readiness and support are accounted for, reducing the risk of delays or failures due to external dependencies.	Subtheme 5.4

	[24] **The framework <u>could</u> account for evolving capabilities and external factors throughout the adoption process.** This requirement allows for adaptability as conditions change, ensuring that projects remain feasible and relevant over time.	Subtheme 5.5 IF1
	[25] **The framework <u>should</u> include a revised implementation plan based on capability re-assessment as input for the full-scale deployment.** This requirement ensures the evolving capabilities or external factors are considered for the implementation.	Subtheme 5.5 IF1
	[26] **The framework <u>should</u> emphasize that completed projects should provide feedback and lessons learned for future projects.** This requirement ensures that continuous improvement is integrated into the framework, enhancing future project success.	Subtheme 5.6 IF3
Design Principle for IoT Project Evaluation	[27] **The framework <u>should</u> incorporate cost-benefit analysis as a key component of the post-launch review.** This requirement ensures that financial performance is evaluated after the project's implementation, allowing leadership to assess the project's long-term value.	Subtheme 5.3

In order to incorporate the new set of requirements into the IoT Technology Adoption Framework, the next section will address the stage-gate process, each stage individually, and the project evaluation metrics in this order. The modifications and enhancements will be explained for each stage to provide clarity on how they align with the overall framework.

6.2 Revised IoT Technology Adoption Framework

For improved clarity of the overall process, the stage-gate framework is revised first to include insights related to timelines and ownership at each stage. In order to achieve this, the interview results were previously aggregated in Table 14. The updated and integrated process is presented in **Figure 9** below:

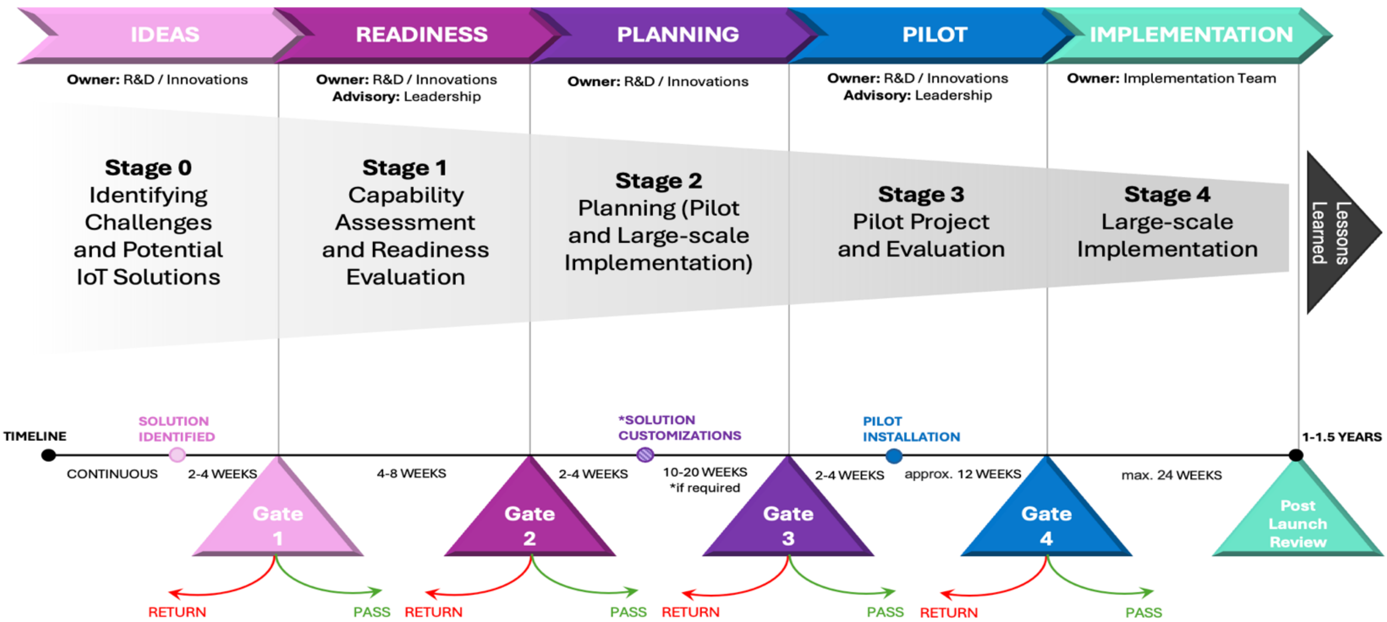

Figure 9: Updated Stage-Gate Process for IoT Technology Adoption

It became evident during the analysis that timelines for new technology adoption can vary significantly, and the values provided in the framework are only approximate guidelines based on expert opinions (requirement [21]). Therefore, these should not be viewed as strict deadlines, and it is important to accommodate potential variations. For Stage 0, identifying challenges and potential solutions is a continuous process; once a solution is found, a timeline of 2-5 weeks is suggested for selecting the best-fit alternative. Stage 1 is crucial, as it lays the foundation for IoT technology adoption. While Interview 2 suggested that once experience is gained and the process is streamlined, this stage could be completed in approximately 2 weeks, this timeline could actually reach 4-8 weeks under initial circumstances. As ITAF aims to provide structure for IoT adoption to combat existing issues, this analysis operates on the assumption that a non-streamlined timeline is preferred. Stage 2 introduces a new step for solution adjustment and customization, which could extend its timeline to 12-24 weeks. Without customization, this stage could be completed within 2-4 weeks, which is why this component is added with an asterisk in the overview. For Stage 3, a new element for pilot installation is also added, as it was highlighted during interviews that this step can take up to a month and is vendor-dependent. Pilot testing itself is estimated to take approximately 12 weeks. Stage 4, the full-scale deployment, is highly dependent on the scope and complexity of the technology and project. Interviewees agreed that for a rollout to succeed, it should be completed within 24 weeks (6 months). Delays beyond this point could increase risks related to organizational changes, external factors, or price fluctuations, further impacting the project.

In terms of ownership (requirement [21]), R&D or Innovations teams typically lead Stages 0-3, with a handover occurring at Gate 4 for Implementation Teams to take ownership in Stage 4. This conclusion was drawn directly from subthemes 4.1, 4.2, and 4.4. Leadership, although not holding primary ownership, plays a key role in resource allocation at Stage 2 and approval of full-scale rollout at Gate 4. Other stakeholders, such as vendors, operations teams (end-users), finance, legal, procurement, and health & safety teams, contribute at various stages. As highlighted in subtheme 4.3, while a higher number of stakeholders can lead to delays, their involvement is essential for the project's success.

Finally, **Figure 9** now also shows that lessons learned from each IoT technology adoption project will feed into future initiatives (requirement [26]), supporting continuous learning and streamlining the overall adoption process. The next section will zoom in on the revised version of each stage individually.

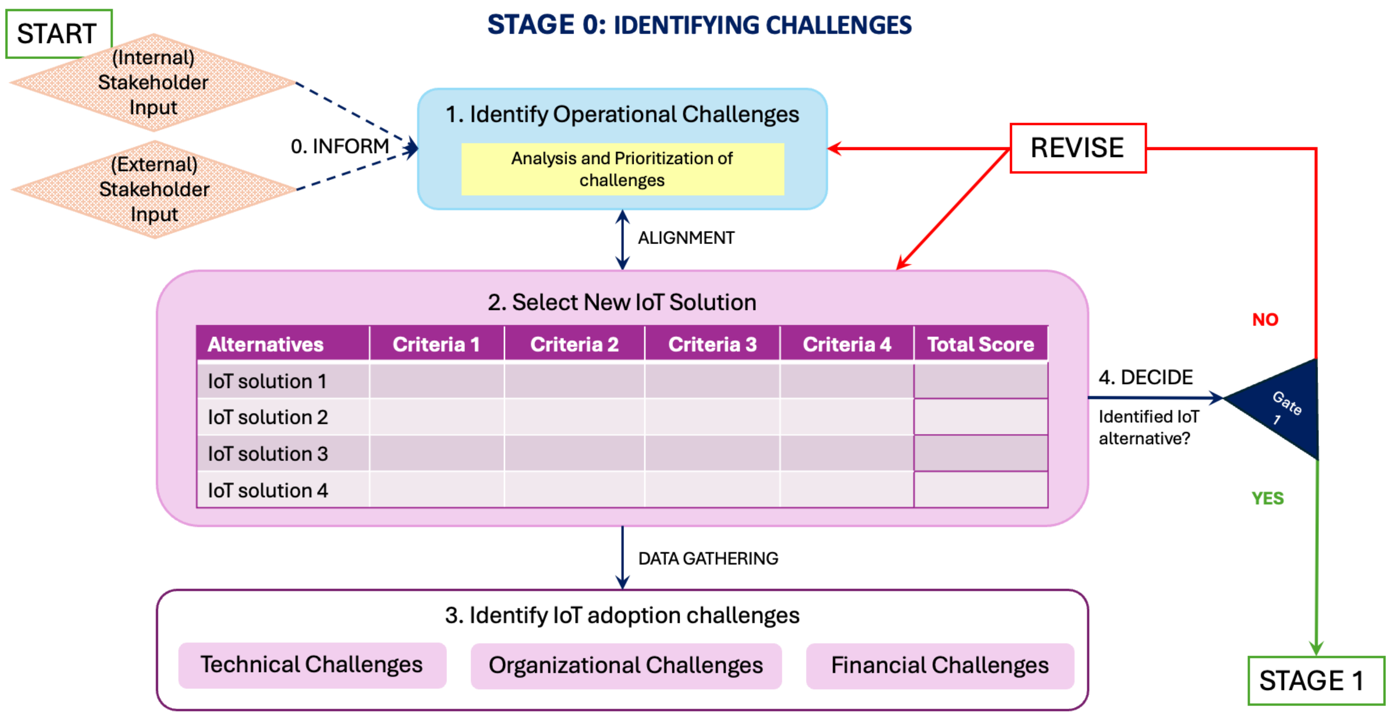

Figure 10: ITAF Stage 0 Diagram (Updated)

In Stage 0, the only adjustment involves separating the input from internal stakeholders (such as operations teams and leadership) and external stakeholders (such as vendors). This separation emphasizes the importance of technology vendors proposing innovative solutions for operational improvements that the company might not have considered otherwise (requirement [23]). Vendors with a business model centered on innovation are well-informed about the latest technological advancements and can play a critical role in identifying relevant IoT solutions. Otherwise, no additional changes were made to Stage 0 following the evaluation. The updated diagram for Stage 0 is depicted in **Figure 10**.

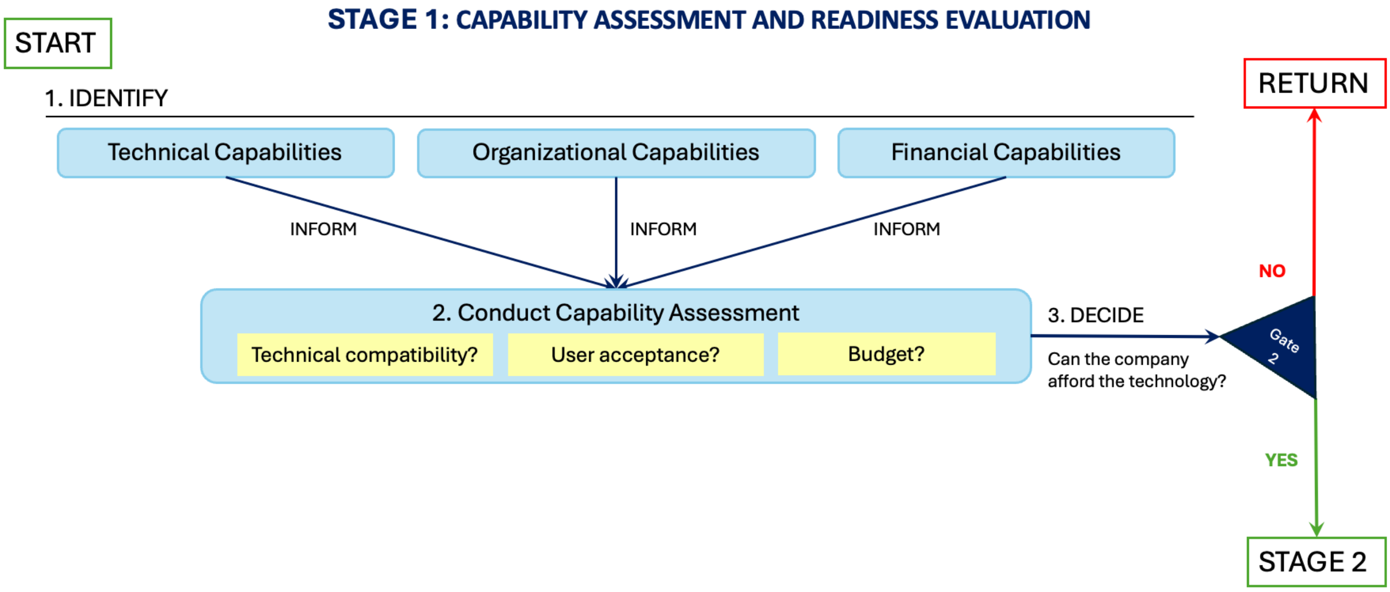

Figure 11: ITAF Stage 1 Diagram (Updated)

No necessary modifications were found for Stage 1 of the IoT Technology Adoption Framework following the evaluation. This stage, which focuses on assessing the company's technical, organizational, and financial capabilities, remains unchanged as it continues to align with the core objectives of ensuring that the organization is fully prepared to support the selected IoT solution. The same diagram for Stage 1 is depicted in **Figure 11**.

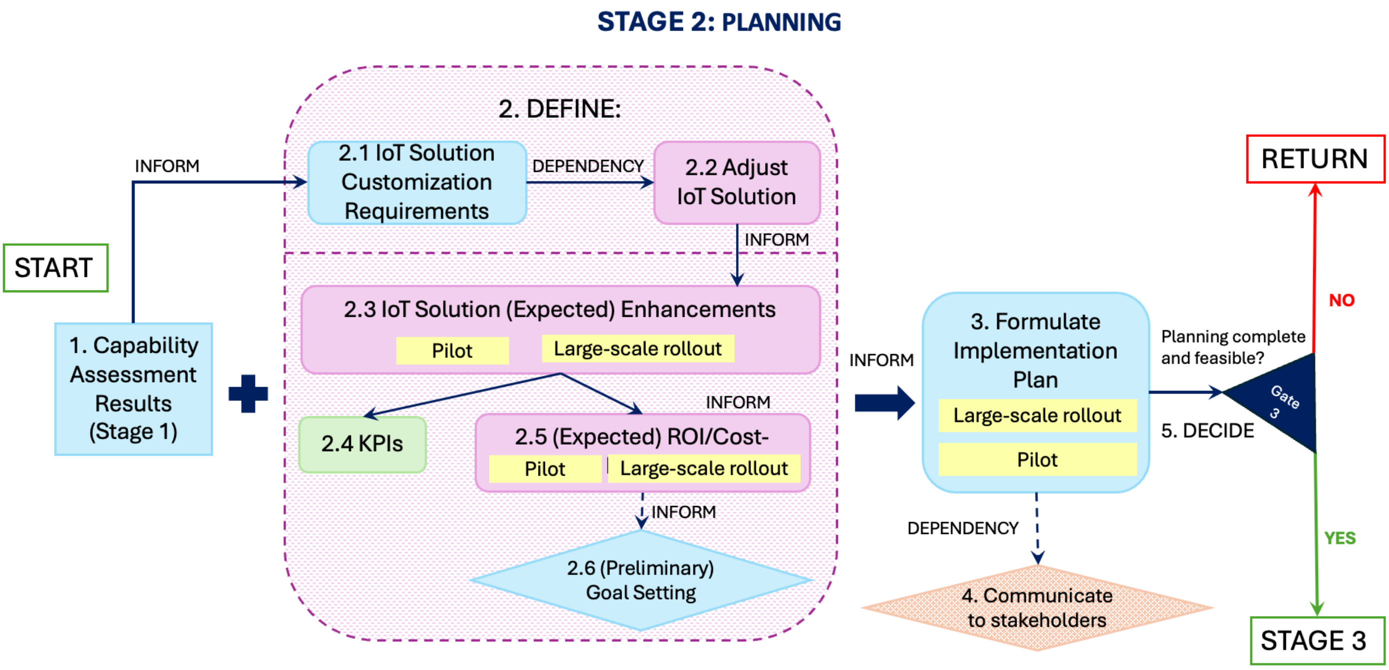

Figure 12: ITAF Stage 2 Diagram (Updated)

Stage 2 incorporates two additional steps regarding pilot preparation, i.e., the fine-tuning of the IoT solution before an implementation plan for both the pilot and large-scale rollout can be formulated (requirement [22]). These steps address any specific customizations or adjustments the company may need to make to the IoT solution based on the results of the capability assessment. The adjustment process is carried out in collaboration with the vendors (requirement [23]) and will directly influence the expected solution enhancements, as well as the KPIs and projected returns. For instance, if adjustments to the solution require substantial investment, the anticipated returns may be lower. This fine-tuning process also impacts the planning step, as any additional changes to existing infrastructure or systems must be factored in for both the pilot and the large-scale implementation stages. The new diagram for Stage 2 is depicted in **Figure 12**.

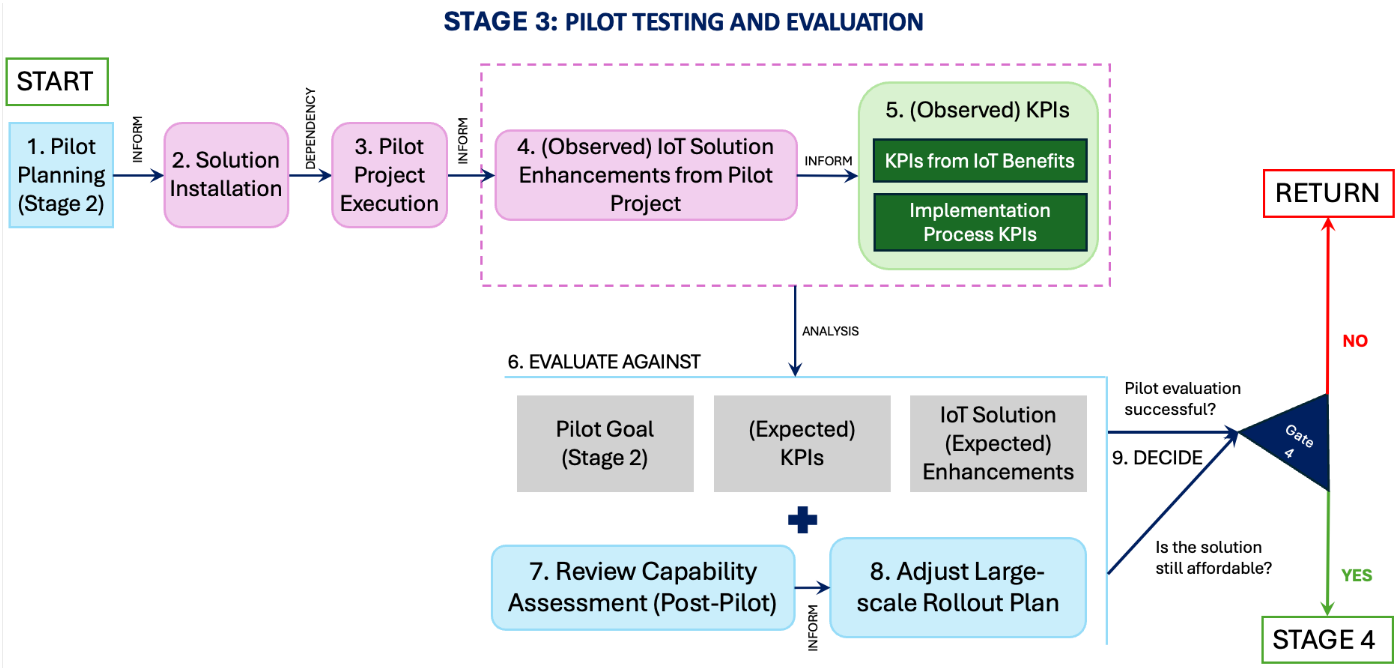

Figure 13: ITAF Stage 3 Diagram (Updated)

Another three steps were added to Stage 3 of the framework. The updated diagram for Stage 3 is depicted in **Figure 13**. First, based on the pilot planning established at Stage 2, the new IoT technology first needs to be installed at the designated pilot site before proceeding to actual testing (requirement [22]). This installation process should be accounted for separately, as it significantly impacts the overall timeline. The installation is also completed in collaboration with the vendors to ensure proper setup and readiness for the pilot phase.

The second new element occurs after the pilot evaluation but before the go/no-go decision at Gate 4 and involves a review of the capability assessment from Stage 1 (requirement [24]). Given that the pilot installation and testing may last 3-4 months, it is important to reassess whether any capability changes have occurred since the initial assessment. These changes may include shifts in organizational structure, vendor support, prices, market conditions, or other external factors. Ensuring that the company remains capable of supporting full-scale deployment is essential before proceeding.

Based on the capability reassessment, adjustments to the implementation plan from Stage 2 may also be necessary (requirement [25]). These adjustments should be carefully considered before the go/no-go decision at Gate 4, as they introduce a new critical question: "Can the company still afford the IoT solution given the current capabilities?". Only if the answer to both this and the pilot success is “Yes” can the project move forward to Stage 4. If either question receives a negative answer, further revisions will be required. As highlighted in the interview analysis, this gate represents the highest risk of project abandonment or delays in the entire process (subtheme 1.5), a scenario previously referred to in the literature as “pilot purgatory” (Bhalekar & Eloot, 2018). However, if the framework has been followed correctly up to this point, the full-scale rollout should proceed smoothly and efficiently.

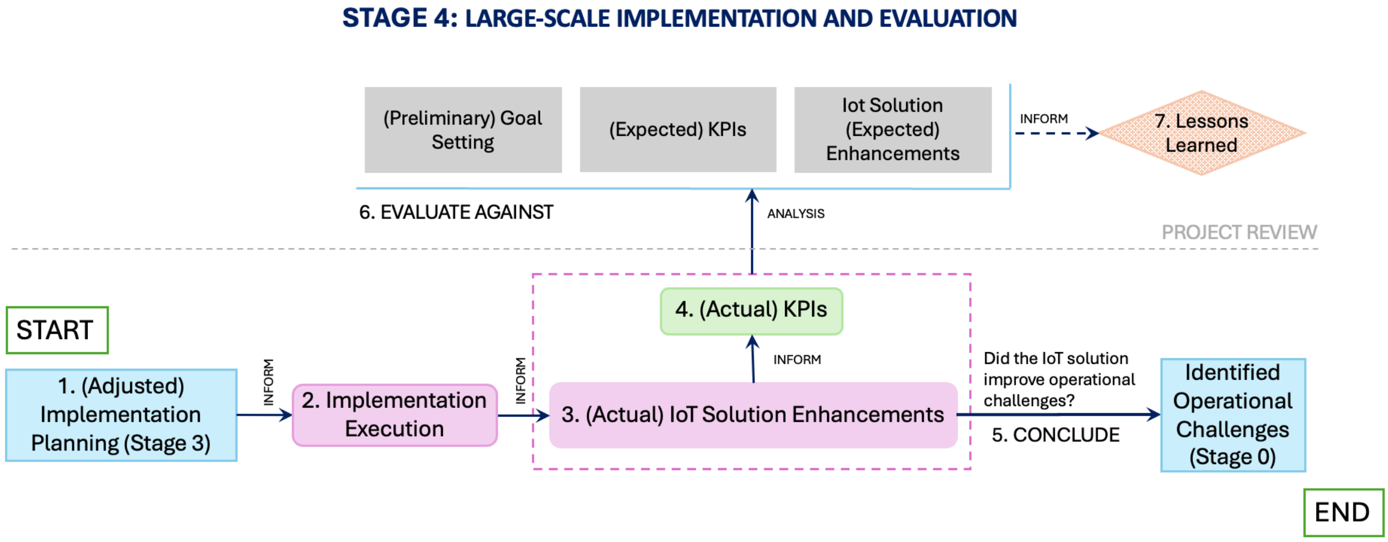

Figure 14: ITAF Stage 4 Diagram (Updated)

The only change identified for Stage 4 concerns the implementation plan, which serves as the input for the execution phase. Following the revision of Stage 3, this should instead be the "adjusted version of the implementation plan" formulated previously (requirement [25]). The potential for this adjustment was already identified as a possibility during the literature review in Chapter 3. However, the interview analysis has confirmed that this is a frequent occurrence in practical applications and, as such, should be explicitly highlighted in the framework. No other changes were made to Stage 4. The updated diagram for Stage 4 is depicted in **Figure 14**.

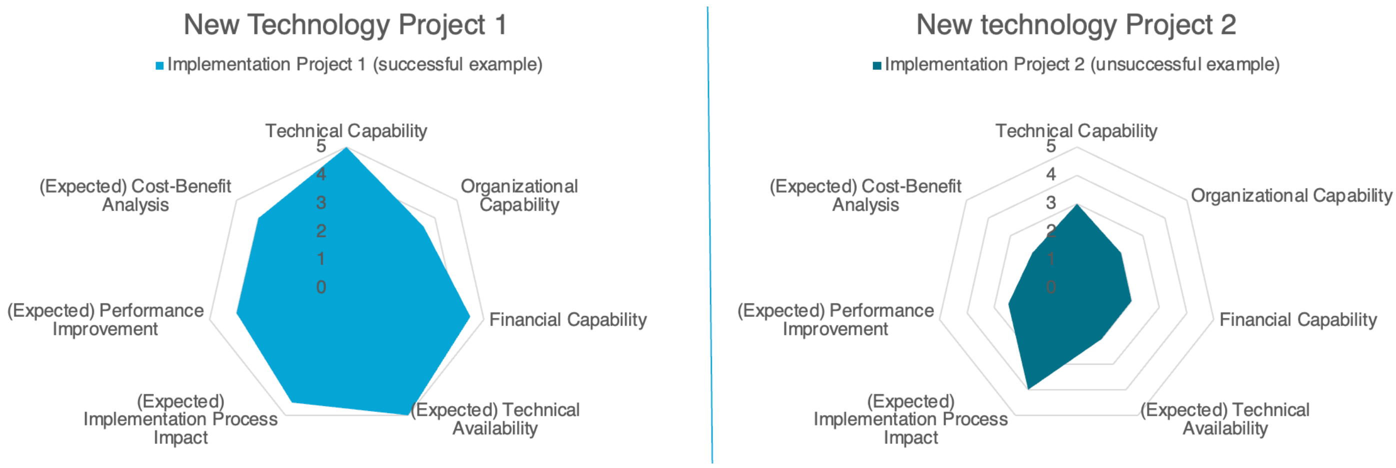

Figure 15: Project Evaluation Metrics Radar Chart (Updated)

Finally, the cost-benefit analysis results were incorporated into the project evaluation metrics (requirement [27]). The updated radar charts for the evaluation metrics are depicted in **Figure 15**. The financial returns of the IoT technology are crucial for leadership to assess the success of the project and make informed decisions for future steps, gates, or initiatives. Additionally, to streamline project reviews during the stage-gate process, all metrics in the framework, except company capabilities, can now include expected values instead of actual results. This adjustment is particularly relevant because, at intermediate stages, many metrics cannot yet be fully observed; thus, evaluations at these points should be based on predicted outcomes. Lastly, to enhance the visualization of the company's IoT technology portfolio during the post-launch review, a comparative analysis of projects using the same radar charts is provided in **Figure 16**.

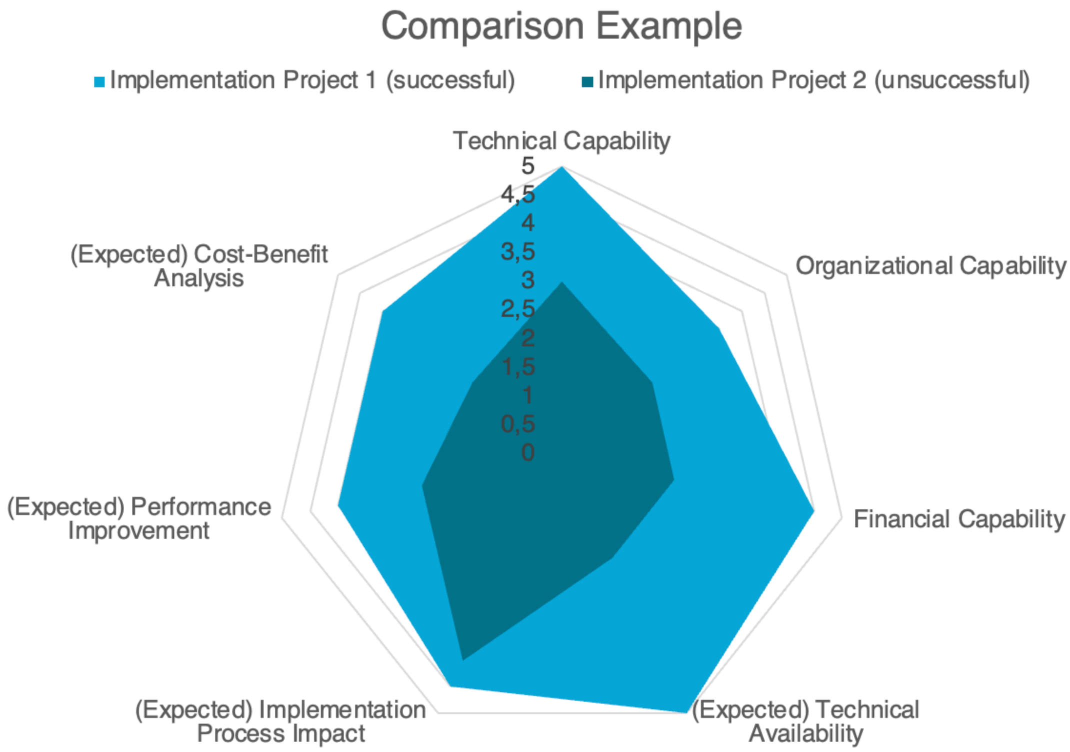

Figure 16: Project Comparison Radar Chart

Chapter Conclusion

This chapter answered sub-question 6 of this study: *"How can the IoT adoption framework be improved based on the evaluation insights to ensure it meets the operational needs of 3PL companies?"*. Following the DSR methodology, this chapter focused on Phase 5: Revision, where the design activity entailed refining and updating the IoT Technology Adoption Framework (ITAF) based on expert feedback and analysis insights from the evaluation phase. As such, in the first section, new requirements were identified from Theme 5 of the interview analysis and the project evaluation sheets, such as the need for vendor collaboration, continuous capability reassessment, and pilot preparation. Section 6.2 then integrated all of the new requirements into the framework, improving each stage of the process. The revisions focused on making the framework more adaptable, operationally feasible, and aligned with the real-world needs of 3PL companies.

For the scope of this thesis, this concludes the revision of the IoT Technology Adoption Framework, corresponding to Phase 5: Revision of the DSR. As established previously in Chapter 2, this study's modified DSR diagram involves only one artifact revision, unlike traditional DSR. This leaves room for further refinement, which will be addressed in the discussion of Chapter 7.

7 Discussion

This chapter addresses the broader implications of the IoT Technology Adoption Framework (ITAF), with a focus on the study findings, potential for generalization, managerial relevance, contributions to the academic and scientific fields, and the framework's limitations. Additionally, directions for future research are proposed to enhance the understanding and application of IoT adoption in the logistics industry and beyond.

7.1 Findings

The findings of this study reveal the intricacies of IoT technology adoption within the logistics industry, particularly in the case of third-party logistics (3PL) companies. The research identifies multiple challenges, primarily rooted in technical, organizational, and financial domains, as examined through both the literature review and the practical evaluation at FedEx Europe. The development of the IoT Technology Adoption Framework (ITAF) aims to provide a structured methodology to mitigate these challenges, and its evaluation and subsequent refinement highlight its potential for enhancing the IoT adoption process in real-world applications.

One of the first findings is the necessity for a stage-gate framework that systematically addresses the various phases of IoT adoption. The original literature outlined several risks associated with IoT implementation, particularly the challenge of transitioning from pilot testing to large-scale deployment, which often leads to projects being stalled or abandoned. This phenomenon, known as "pilot purgatory", was highlighted in both the literature and the practical evaluation, where IoT projects fail to progress beyond pilot stages due to inadequate resource allocation, insufficient technical capability, or organizational inertia. The ITAF effectively addresses this issue by breaking the adoption process into distinct stages, each with defined deliverables and decision gates, providing companies with a clear roadmap for decision-making. By enabling organizations to evaluate projects at key points, they can make informed decisions on whether to proceed, revise, or abandon projects, thus reducing the likelihood of failure due to unforeseen challenges. It also emphasizes the need for well-defined roles and responsibilities, linking to the next critical factor: stakeholder involvement.

An additional key finding from the research is the importance of stakeholder involvement and ownership at each stage of the IoT adoption process. The case evaluation at FedEx revealed that unclear ownership, or the involvement of a high number of stakeholders, both internal and external, often causes delays in the adoption process. A lack of clearly defined roles, particularly during cross-functional collaboration, leads to confusion and inefficiencies. As such, the revised ITAF emphasizes the importance of assigning clear stakeholder ownership at each gate, ensuring accountability and better coordination throughout the process. This refinement was directly informed by both the gaps identified in the literature and practical insights from FedEx employees, addressing a critical bottleneck that frequently disrupts IoT implementation efforts.

The importance of assessing all company capabilities early in the IoT adoption process was one of the key insights derived from both the literature and the FedEx case study. Organizational capability was the first to be emphasized in the literature, as workforce readiness and change management were identified as critical factors in the success of IoT implementation. Building on this, ITAF expanded the scope to include early assessments of not only organizational but also technical and financial capabilities. The need for a thorough financial capability assessment was further confirmed during the FedEx interviews, where participants stressed that budget constraints and ROI expectations could stall IoT projects before full-scale deployment. By ensuring a comprehensive evaluation of these three dimensions early in the process, ITAF helps companies anticipate and address potential barriers before significant resources are invested. This early-stage assessment mitigates the risk of project delays or failures due to insufficient infrastructure, inadequate workforce preparedness, or financial limitations.

Another critical finding from the study is the need for strategic alignment between IoT initiatives and the company's broader objectives. Beyond assessing internal capabilities, companies must ensure that their IoT initiatives contribute to long-term strategic goals. ITAF introduces a structured evaluation of IoT projects through a set of project evaluation metrics, which allow companies to measure not only the technical and financial feasibility of IoT solutions but also how well these solutions align with strategic goals. This alignment ensures that IoT initiatives contribute to long-term operational improvements and measurable returns, which was a key concern highlighted by FedEx employees during the evaluation. This focus on strategic alignment further strengthens the framework's ability to drive successful outcomes for 3PL companies.

The qualitative analysis at FedEx further underscores the relevance and applicability of ITAF in a real-world setting. FedEx, as a global leader in logistics, faces similar IoT adoption challenges as other 3PL companies, particularly with the integration of new technologies into legacy systems. This is a significant technical challenge that leads to difficulties in scaling IoT projects from pilot tests to full implementation. Moreover, FedEx's case study revealed organizational resistance to change, especially in large international corporations with complex networks and ingrained operational processes. The feedback from FedEx employees was essential for refining the ITAF to improve adoption efficiency and reduce project delays. One notable insight was the suggestion to separate pilot preparation and installation from planning and execution to improve resource planning and avoid unnecessary bottlenecks. The resulting changes were incorporated into the ITAF, highlighting the importance of distinguishing between the technology installation and the execution of a pilot. This ensures that vendor and solution readiness, as well as other preparatory activities, are completed before moving into the critical testing phase.

Another important finding was the necessity of continuous capability reassessment throughout the IoT adoption process. As IoT projects typically span months or even years, both internal and external conditions within a company can shift over time. Organizational changes, price fluctuations, market dynamics, or shifts in resource availability can impact a company's ability to continue supporting the adoption of IoT technologies. The revised ITAF now includes a formal capability reassessment after the pilot phase, ensuring that the organization still possesses the necessary resources – technical, financial, and organizational – to support full-scale deployment. While it remains true that some negative externalities can't be predicted in advance, the formalization of this step raises awareness of their potential occurrence, enabling companies to make informed decisions and prepare contingency solutions. This reassessment ensures that projects remain viable and adaptable to changing circumstances, helping to mitigate the risk of encountering obstacles that were not foreseen at the initial stages of the project.

Financial considerations emerged as another crucial factor influencing IoT adoption decisions. Although operational improvements and efficiency gains are key motivators, some companies emphasize the need for clear financial returns from their technology investments. The study revealed that while many companies recognize the potential long-term benefits of IoT, there is a reluctance to proceed without a strong understanding of the projected financial gains. To address this concern, the ITAF was revised to include a cost-benefit analysis during the post-launch review. This allows leadership to assess the financial impact of IoT projects over the long term, where they may not be immediately visible, providing a quantitative foundation for evaluating the project's success. By integrating this into the framework, companies are better equipped to justify technology investments and ensure alignment with broader financial and strategic goals.

Finally, the findings underscore the importance of incorporating a feedback loop within the IoT adoption process. Lessons learned from completed IoT projects should feed back into the organization's strategy, allowing for continuous improvement in future initiatives. This element of the ITAF emphasizes the need for organizations to build on past successes while avoiding previously encountered pitfalls. By fostering a culture of continuous improvement, companies can become more adept at adopting new technologies and refining their approaches over time. This iterative learning process is especially valuable in industries like logistics, where the rapid pace of technological advancement necessitates agility and adaptability.

Overall, the findings of this study highlight the significant value of a structured, stage-gated framework like the ITAF in managing the complexities of IoT adoption within the logistics industry. By systematically addressing the recurring challenges that companies face, the ITAF provides a practical and scalable roadmap for IoT adoption. The framework’s capacity to evolve based on real-world feedback, as demonstrated through its refinement after the FedEx case study, also underscores its flexibility and adaptability across different contexts within the 3PL sector. This research ultimately shows that with the right tools and structured processes, companies can better navigate the complexities of IoT adoption and increase their chances of successful implementation.

7.2 Potential for generalization

The IoT Technology Adoption Framework (ITAF), developed and refined through a combination of literature review and expert input from FedEx, exhibits strong potential for generalization beyond its current evaluation. While this research has focused specifically on the logistics industry and FedEx as a practical application, the framework’s core components – such as the stage-gate process, capability assessment, and project evaluation metrics – can be effectively applied across different sectors that are undergoing technological transformations. This includes not only logistics companies of varying sizes but also industries like healthcare, manufacturing, and retail, which increasingly rely on IoT technologies to enhance operational efficiency, reduce costs, and improve customer service. The framework's ability to incorporate vendor management, cost-benefit analysis, and continuous capability reassessment further strengthens its adaptability across various industries and organizational scales. The inclusion of vendors as key stakeholders at multiple stages ensures that external dependencies are accounted for, making the framework applicable in industries that rely on external partnerships, such as healthcare and manufacturing. Likewise, the emphasis on financial evaluation through cost-benefit analysis allows companies in capital-intensive industries to justify long-term investments in new technologies.

Within the logistics industry, ITAF’s structured approach is adaptable to any 3PL company, regardless of size or regional presence. The challenges FedEx faces in integrating IoT solutions, such as managing legacy systems, organizational inertia, and resource allocation, are common across many logistics companies. As a result, ITAF’s systematic breakdown into distinct phases ensures that these universal challenges are addressed in a way that any logistics provider, from regional to global companies, can benefit. This means smaller logistics companies can leverage ITAF to ensure successful adoption while minimizing risks, while larger multinational organizations can use the framework to unify their approach across various regions and teams, ensuring consistency and preventing duplication of efforts.

Furthermore, ITAF holds significant potential for scalability within complex organizations, such as FedEx. As observed from the interview analysis, FedEx employees highlighted the value of the framework in providing consistency across regions while allowing flexibility for regional adaptation. ITAF could be implemented globally at an organizational level with one aligned strategy, where Stages 0 to 2 (challenge identification, capability assessment, and planning) are centralized, ensuring a unified strategic direction for technology adoption across the organization. For Stages 3 and 4 (pilot testing and full-scale implementation), regional teams could then tailor the framework to address local challenges and resource availability, thus allowing for scalability without losing the benefits of centralized decision-making. This approach prevents duplication of efforts and ensures that lessons learned in one region can be applied globally, enhancing efficiency and reducing risks.

The application of ITAF is not limited to IoT technology adoption alone. The framework's principles and steps at each gate can be essential components of any successful technology adoption process. Thus, ITAF can be adapted for the implementation of other emerging technologies, including robotics, artificial intelligence, blockchain, and new automation solutions. By adjusting the specific metrics used in the capability assessment and cost-benefit analysis, ITAF can guide companies through the adoption of non-IoT technologies in the same structured, risk-mitigating manner. This makes the framework versatile and applicable to a wide range of technology projects, providing companies with a reliable methodology for handling complex, transformative innovations across different domains.

7.3 Managerial recommendations

The IoT Technology Adoption Framework (ITAF) offers several key managerial insights that can help companies improve the efficiency and success of their IoT technology adoption projects, particularly for technology managers and engineers. The stage-gate process within ITAF provides a structured roadmap for managing complex technology rollouts, ensuring that projects maintain momentum and mitigating risks, especially in large organizations where delays often occur due to the involvement of multiple stakeholders. Defining ownership at each stage ensures accountability and smooth decision-making, helping companies avoid common bottlenecks that arise during cross-functional collaborations. This is particularly important in phases like pilot testing and full-scale implementation, where coordination between different departments is critical.

Financial planning is another crucial aspect emphasized by ITAF. Early financial assessments allow managers to make informed decisions about resource allocation, helping prevent costly missteps. By incorporating financial evaluations into the earlier stages of IoT projects, companies can avoid overcommitting resources to initiatives that may not deliver expected returns. Furthermore, involving vendors early in the adoption process ensures technical challenges are addressed upfront, which reduces the likelihood of unforeseen issues derailing projects later on. The ITAF also encourages managers to take into account their organization’s technical limitations, which may require additional development or customization for the new technology solution to meet specific operational needs. These technical adjustments should be factored into both resource allocation and project timelines, ensuring that sufficient budget and time are available to address any necessary modifications. Planning for these contingencies at early stages may prove more difficult and require accurate estimations, but having a solid foundation that can later simply be adjusted would help prevent delays and unexpected costs during the stages of implementation.

In addition to the technical and financial considerations, change management plays a pivotal role in the successful adoption of IoT technologies, a point strongly emphasized by the findings of this research. Implementing IoT solutions often requires significant changes in organizational processes, workflows, and employee responsibilities. Without proper change management strategies, these shifts can result in resistance from staff, especially in companies with established operational routines. Ensuring workforce readiness and fostering a culture that is open to technological innovation is crucial for avoiding disruptions during IoT adoption. Training programs, clear communication of the benefits of IoT, and ongoing support for employees adapting to new systems are essential components of effective change management. By integrating change management into the ITAF framework, managers can address potential resistance and enhance the overall adoption process, ensuring that both employees and the organization are prepared to leverage the full benefits of IoT technologies. This not only smoothens the transition to new technological systems but also fosters long-term acceptance and success.

Managers also need to consider the broader implications of IoT adoption. Process automation, enabled by IoT, offers significant opportunities to improve operational efficiency, but it requires careful planning and commitment. To fully benefit from IoT, companies may need to pursue multiple projects to move toward fully automated operations, such as smart warehouses. However, this brings with it the need to balance automation's advantages with potential ethical concerns, particularly regarding job reductions. By gradually integrating automation technologies and maintaining a focus on training employees, managers can alleviate these concerns while still achieving their goals.

Additionally, ITAF encourages continuous improvement by promoting post-launch reviews and incorporating lessons learned from each project into future initiatives. This feedback loop ensures that companies can refine their processes over time, increasing their chances of success in future IoT implementations. For managers, this is essential in industries like logistics, where the fast pace of technological advancements demands constant adaptation and learning.

In summary, ITAF provides managers with a practical, adaptable framework for navigating the complexities of IoT adoption. By focusing on structured processes, financial foresight, vendor collaboration, and continuous improvement, managers can drive successful technology rollouts while aligning with broader organizational goals. This approach not only enhances the potential for operational efficiency but also fosters long-term success in IoT-driven innovation.

7.4 Limitations

While the IoT Technology Adoption Framework (ITAF) offers several advantages, it is not without limitations. One primary limitation is its focus on large-scale organizations, particularly 3PL companies like FedEx. Smaller companies with fewer resources and less complex structures may find it challenging to implement certain aspects. The framework may not fully capture the nuances of small-to-medium enterprises (SMEs) operating with constrained timelines and budgets, making it less adaptable for those contexts without modification.

Another limitation is that only one evaluation iteration was conducted, which deviates from the iterative nature of Design Science Research (DSR). DSR typically advocates multiple cycles of testing and refinement. However, due to time constraints and the scope of this thesis research study, only one evaluation loop was completed. More iterations would help to further refine and improve the ITAF, ensuring greater applicability across different sectors.

The qualitative nature of the evaluation, which was based on interviews, also presents a limitation. While valuable insights were obtained from industry experts at FedEx, the use of qualitative data, rather than quantitative, restricted the ability to assess measurable outcomes. Additional evaluation would be useful through implementing practical, real-world applications of the ITAF in operational environments, yielding quantifiable data and concrete performance metrics. Additionally, the small sample size of interview participants, mostly from innovation and project management teams, may have limited the breadth of perspectives. Involving a wider range of stakeholders and increasing the variety of roles and responsibilities – such as operations staff, vendors, and top management – would provide a more comprehensive view.

A further limitation arises from the rapid pace of IoT technology advancements. With new technologies entering the market frequently, companies may face the issue of completing the adoption of one system just as a newer, more advanced version becomes available. This rapid evolution can complicate long-term planning and make it difficult to keep up with the latest developments. While ITAF provides a structured approach to adoption, it needs to remain flexible enough to adapt to these fast changes without becoming overly rigid. This limits its specificity in a trade-off against practical relevance.

Lastly, unpredictable challenges such as market shifts and external factors can affect implementation timelines. These timelines, while provided as guidelines, should be treated flexibly. Additionally, elements like KPIs and implementation plans are technology-specific and must be adapted by users to their specific needs; they were, therefore, not addressed in detail in the framework.

8 Conclusion

This study presents the development of the IoT Technology Adoption Framework (ITAF), designed to answer the main research question: “Which structured framework can be developed for 3PL companies to adopt IoT technologies for their operations?”. The main design objective of this study is to create a structured, adaptable framework that supports 3PL companies in overcoming the specific challenges associated with IoT adoption, ensuring a systematic pathway through each stage of the process to mitigate risks and improve the success rate of technology implementation. The ITAF offers a systematic and adaptable approach for logistics companies that want to improve their new IoT technology adoption processes and better navigate the technical, organizational, and financial challenges inherent in such initiatives. This study was conducted with a particular focus on mitigating risks and improving the success rate of IoT technology implementation. The first sub-question centered around exploring the potential of IoT technology in the logistics sector and aimed to raise awareness about the significant benefits it would eventually bring. Through a literature review, several such advantages were highlighted, such as real-time asset tracking, predictive maintenance, and improved operational efficiency, which could create considerable competitive advantage for 3PL companies. The adoption of IoT was found to align with the strategic goals of 3PL companies by enabling enhanced data-driven decision-making and operational flexibility. Then, the second sub-question focused on the reasons why 3PL companies are lagging behind in adopting cutting-edge technologies like IoT despite the clearly established benefits. The study identified several challenges that 3PL companies face, which could be grouped into three overarching categories: technical, organizational, and financial. These include the integration of IoT into legacy systems, organizational resistance to change, and the financial burden of implementing new technologies. The three types of challenges became the building foundation of the designed framework as it seeks to provide solutions for mitigating them. To further inform the framework design and objective and, as such, answer the third sub-question, the research analyzed established models in literature and built a set of requirements to guide the development of ITAF. The need for a stage-gate framework design was quickly made apparent, as it introduces systematic evaluations of capability readiness at key stages of adoption. Therefore, the ITAF prototype was designed to include all initial requirements from the literature and with the objective of mitigating IoT adoption challenges. The step-by-step approach answers the fourth sub-question and includes the following key stages of adoption: identifying challenges, capability assessment, planning, pilot testing, and large-scale implementation. Each stage is paired with decision gates to ensure companies can assess progress and make adjustments as needed. The framework also provides a guideline for project review using a comprehensive set of evaluation metrics: technical, organizational, and financial capabilities, technical availability, implementation process impact, and performance improvement. To answer the fifth sub-question, the prototype was evaluated within a practical context through expert interviews at FedEx Europe, from which a new set of requirements resulted. Additionally, the framework was evaluated as grounded in real-world applications, well-structured, comprehensive, and scalable. Lastly, in answer to the sixth and final sub-question, improvements were made based on the new requirements for each of the stages, timelines, and ownership, as well as the addition of another project evaluation metric: cost-benefit analysis. As such, the final ITAF framework proposed by this study provides a robust, adaptable guideline for any 3PL company that seeks to improve its IoT technology adoption landscape for greater competitive advantage, operational efficiency, and customer satisfaction.

8.1 Relevance for MSc program

This research is highly relevant to the Master's program in Complex Systems Engineering and Management (CoSEM), as it addresses the complexities of socio-technical systems in the logistics sector, particularly third-party logistics (3PL) providers. The logistics industry operates as a socio-technical system due to the interdependence between technology and a broad network of social actors, including service providers, customers, vendors, and other stakeholders. The technical aspect is represented by the IoT technologies and other digital innovations that enable service delivery, while the social aspect comes from the interaction between logistics providers, their customers, and other stakeholders across the supply chain. By analyzing how IoT adoption impacts both the technological infrastructure and organizational dynamics within 3PL companies, the study highlights the critical balance between technology and the human factors that drive service delivery. Customers, as primary drivers, expect seamless, real-time logistics services, which require advanced technical systems. However, IoT adoption in 3PLs is often slowed by organizational resistance to change, financial constraints, and the challenges of integrating new technologies into legacy systems. This demonstrates the importance of managing these socio-technical complexities, which is a core element of CoSEM's approach to understanding and solving problems within complex systems.

Additionally, the logistics sector, as both a public and private domain, exemplifies the intersection of these two spheres. On the public side, logistics operations are vital to the global economy and societal well-being, enabling cross-border trade and access to goods and services. On the private side, logistics companies operate within competitive markets, where technological innovation is essential for maintaining profitability and customer satisfaction. This duality reflects CoSEM's focus on balancing public and private values, particularly in the implementation of technologies like IoT, which can enhance operational efficiency but also raise concerns about job displacement and the socio-economic impacts of automation.

Overall, this study is a fitting example of CoSEM's emphasis on integrating engineering solutions within socio-technical systems. It addresses not only the technical challenges of IoT adoption but also the organizational and social considerations necessary for a structured framework to managing innovation in logistics.

8.2 Academic Contributions

This research contributes significantly to the growing body of literature on IoT adoption, particularly within the logistics industry, by directly addressing the research gap identified in Section 1.3. Specifically, this gap arises from the lack of structured methodologies in current literature to guide IoT adoption for large, traditional 3PL companies that manage complex operational networks and legacy systems. Unlike eCommerce companies, 3PL providers operate within multifaceted supply chains and often depend on legacy infrastructure, making it challenging to integrate new technologies effectively. This complexity has led to an underrepresentation of such specific IoT adoption frameworks in the existing literature. By developing a comprehensive, stage-gate framework for IoT adoption into complex logistical systems, this study fills the literature gap, where limited and older structured methodologies exist that do not account for the increasingly fast pace of technology advancements today. Many existing frameworks lack the specificity needed to address the multifaceted challenges posed by rapid technological developments in IoT. This research provides the IoT Technology Adoption Framework (ITAF), which is designed to guide companies through the intricate process of IoT technology adoption, offering a structured, step-by-step methodology that aligns with the operational realities of 3PL companies.

The ITAF framework offers a valuable contribution to both academic research and industry practice by integrating theoretical insights with empirical data. Its development and application within FedEx, a global logistics leader, demonstrate the framework's practical relevance and effectiveness. FedEx's case evaluation highlights how the structured adoption process can be implemented in real-world scenarios, providing concrete evidence of its utility in addressing the complexities of IoT implementation in large, global organizations. This empirical grounding adds to the robustness of the framework, offering a new avenue for future research focused on refining IoT adoption strategies across various industries.

Additionally, this research builds on previous work by incorporating a more holistic view of the IoT adoption process. The integration of capability assessments, financial analysis, and vendor management into a structured process not only addresses organizational readiness but also ensures a comprehensive evaluation of technical and financial feasibility at each stage of the adoption lifecycle. This more nuanced approach expands upon existing models, emphasizing the importance of early-stage assessments to preempt potential challenges. However, unlike many existing academic models that tend to overlook the financial aspect as a critical factor, ITAF emphasizes the necessity of early financial assessments to ensure long-term project viability. By focusing on these aspects, ITAF bridges the gap between innovation theory and its practical application in large-scale organizations.

By contributing a structured, adaptable framework that addresses both theoretical gaps and practical challenges in IoT adoption, this research lays the groundwork for ongoing academic inquiry into how large organizations can effectively manage technology adoption in a fast-evolving landscape.

8.3 Future research

Future research on the IoT Technology Adoption Framework (ITAF) should focus on expanding its applicability and validation across a broader range of industries and organizational sizes. While the framework has demonstrated potential for generalization, particularly within the logistics sector, further empirical studies are needed to test its effectiveness in other industries such as healthcare, retail, and manufacturing. These sectors, which also face significant operational challenges, are increasingly integrating IoT technologies, and validating ITAF in these contexts would confirm its adaptability. Additionally, research should explore how ITAF can be scaled down for small-to-medium enterprises (SMEs) with limited resources. SMEs often operate under more constrained budgets and shorter timelines, so understanding how the framework can be tailored to meet their needs would be useful for broader applicability.

An important area for future exploration is the integration of complementary emerging technologies such as artificial intelligence (AI) and blockchain with IoT. As IoT systems evolve, they are becoming increasingly reliant on these technologies to enhance data processing, security, and automation. Research into how AI and blockchain can be incorporated into ITAF's stages – capability assessment, pilot testing, and full-scale deployment – will provide valuable insights for organizations undergoing holistic digital transformation efforts. This could further enhance ITAF's ability to guide companies through the complexities of adopting multiple interrelated technologies, creating a more comprehensive digital transformation framework.

Moreover, future research should focus on incentivizing companies to invest in technology when the returns are not immediately visible. IoT adoption often requires significant upfront investments, with the financial benefits accruing over the long term. Investigating strategies to encourage organizations, particularly in industries with thin profit margins, to commit to these investments despite the delayed returns would be a valuable contribution. Understanding how companies can be encouraged to take on such high-risk, high-reward initiatives could improve the adoption rates of transformative technologies like IoT.

Longitudinal studies are another key area for future research. Investigating the long-term impact of IoT adoption using ITAF can provide deeper insights into how organizations sustain the benefits of these technologies over time. Such studies would assess how initial IoT implementations affect organizational performance and how lessons learned from early projects contribute to future technology adoption efforts. Understanding these long-term dynamics is crucial for ensuring that companies do not just implement IoT solutions, but also continuously improve upon them to realize ongoing operational efficiencies and strategic advantages.

Finally, further research should continue to refine ITAF by addressing the limitations discussed in section 7.4. As mentioned previously, conducting additional iterations of the framework's evaluation using more comprehensive, quantitative methods would solidify its robustness. Future studies could include practical applications in operational environments where data on measurable outcomes, such as cost savings and productivity improvements, could provide empirical validation. Expanding the range of interviews to include different stakeholders, such as operations staff, top management, vendors, and procurement specialists, would also help in capturing diverse perspectives, leading to more refined insights on IoT adoption challenges.

In conclusion, while the ITAF offers a structured, adaptable approach for IoT adoption, this study opens up several opportunities for further research, particularly in validating its effectiveness across different industries, organizational sizes, and evolving technological landscapes.

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A

Literature review

A.0.1: Literature search and selection

The literature search and selection process for identifying relevant sources on Internet of Things (IoT) technologies in logistics involved a systematic approach to ensure the inclusion of diverse and credible academic and industry-focused resources. The search aimed to explore key IoT applications, benefits, and challenges specific to third-party logistics (3PL) and related sectors, addressing both theoretical perspectives and practical implementations. The initial phase involved keyword-based searches in prominent academic databases such as *IEEE Xplore*, *ScienceDirect, ResearchGate,* and *Springer*. The search spanned publications from recent years (no older than 2010, preferably published after 2015) to capture current trends and emerging applications of IoT in logistics.

Selection Criteria and Process
The selection criteria emphasized peer-reviewed journal articles, conference proceedings, and reputable industry reports that contributed either foundational knowledge or recent advancements in IoT technologies applied to logistics and supply chain management. The papers had to be accessible via TU Delft University login. An initial broad search using keywords such as "IoT in logistics," "smart logistics," "smart warehouses," "IoT supply chain," and "IoT 3PL" yielded tens of thousands of results. To refine this pool, a targeted approach was applied, starting with an examination of several top results to identify key themes. Subsequently, more specific searches were conducted using keywords related to individual IoT technologies, such as "IoT RFID 3PL logistics" and "IoT predictive maintenance logistics," which reduced the results to a few thousand. Further narrowing was achieved by excluding articles focused on topics outside the study's scope, including sustainability, emissions, artificial intelligence, digital twins, blockchain, lifecycle management, etc. Abstracts were then skimmed to eliminate articles that were overly brief or that primarily focused on solution designs without practical implications. Priority was given to studies with higher citation counts, while those addressing multiple IoT technologies in logistics were retained for well-established technologies (e.g., RFID, GPS). For niche technologies with fewer sources, such as smart shelves or IoT-specific cloud computing in logistics, papers providing detailed insights were included.

The final selection (as seen in **Table A.0**) represents a balance of one-third being foundational studies (published 2012-2017) establishing the baseline for understanding IoT's role in supply chain management and logistics, along with two-thirds more recent analyses (published 2018-2022) addressing the evolving capabilities and challenges of IoT in smart logistics and Industry 4.0. Specific studies on evolving technologies, including AMRs and smart shelves (e.g., Hassan, 2020; Tang, 2020), were selected to provide a comprehensive view of the technological components that underpin IoT systems in logistics. This collection of 15 references encompasses a broad spectrum of topics, including essential IoT technologies like GPS and RFID, as well as advanced solutions such as IoT-based predictive maintenance and cloud computing. Together, these sources offer theoretical insights and practical considerations for IoT implementation, directly supporting the study's aim to provide actionable guidelines for IoT adoption within the logistics sector.

Table A. 1: Selected Scientific Research Papers

#	Authors	Publication Year	Title	Focus
1	Ben-Daya, M., Hassini, E., & Bahroun, Z.	2017	Internet of things and supply chain management: A literature review	IoT in supply chain management
2	Fernie, J., & Sparks, L.	2021	Global logistics: New directions in supply chain management	Logistics and supply chain management overview
3	Hammoudi, A., Aliouat, Z., & Harous, S.	2018	IoT-based predictive maintenance: Challenges and implementation	Challenges in IoT-based predictive maintenance
4	Hassan, A., Abdul Rahman, M. S., Md Shah, W., Othman, M. F. I., & Mansourkiaie, F.	2020	Internet of Things based smart shelves prototype implementation	IoT-enabled smart shelves for inventory tracking
5	Ivankova, G. V., Mochalina, E. P., & Goncharova, N. L.	2020	Internet of Things (IoT) in logistics	IoT in logistics for vehicle and asset tracking
6	Kern, J.	2021	The digital transformation of logistics: A review about technologies and their implementation status	Digital transformation in logistics
7	Khan, M. D., Schaefer, D., & Milisavljevic-Syed, J.	2022	Supply chain management 4.0: Looking backward, looking forward	IoT in smart manufacturing
8	Lee, I., & Lee, K.	2015	The Internet of Things (IoT): Applications, investments, and challenges for enterprises	IoT applications in enterprises
9	Macaulay, J., Buckalew, L., & Chung, G.	2015	Internet of Things in logistics: A collaborative report	IoT in logistics and warehousing
10	Miorandi, D., Sicari, S., Pellegrini, F. D., & Chlamtac, I.	2012	Internet of Things: Vision, applications and research challenges	IoT in logistics and object tracking
11	Silkina, G., & Scherbakov, V.	2019	Logistics of smart supply chains	Logistics in smart supply chains
12	Song, H., Han, H., & Kim, S.	2020	Applications of IoT in smart logistics: A comprehensive survey	IoT in smart logistics
13	Tang, J., & Liu, J.	2020	Research on smart logistics model based on Internet of Things	Cloud computing in smart logistics
14	Whitmore, A., Agarwal, A., & Xu, L. D.	2015	The Internet of Things—A survey of topics and trends	IoT and Big Data in logistics
15	Witkowski, K.	2017	Internet of Things, big data, Industry 4.0—Innovative solutions in logistics and supply chains	IoT, Big Data, and Industry 4.0 in logistics

A.0.2: List of IoT technologies identified in literature

This section provides an overview of the key IoT technologies identified through the literature review. It includes the foundational understanding of the various technologies that play a crucial role in logistics operations.

RFID (Radio Frequency Identification):

- Ben-Daya et al. (2017) discusses RFID as part of IoT in supply chain management.
- Lee et al. (2015) highlights RFID as a core IoT technology, particularly for supply chains.
- Hassan et al. (2020) mentions RFID in smart shelves for tracking inventory.
- Hammoudi et al. (2018) explores RFID as a communication protocol enabling IoT.
- Song et al. (2021) discusses the use of RFID in smart logistics.
- Miorandi et al. (2012) discusses RFID for object identification and tracking.

GPS (Global Positioning System):

- Ivankova et al. (2020) describes GPS in logistics for vehicle tracking.
- Ben-Daya et al. (2017) refers to GPS as part of modern IoT networks.

Smart Sensors:

- Ben-Daya et al. (2017) emphasizes smart sensors for real-time monitoring in supply chains.
- Lee et al. (2015) discusses wireless sensor networks (WSN) in conjunction with IoT.
- Hassan et al. (2020) utilizes smart sensors in IoT-enabled smart shelves.
- Hammoudi et al. (2018) discusses smart sensors enabling IoT applications.
- Song et al. (2021) highlights the role of smart sensors in smart logistics.
- Miorandi et al. (2012) discusses smart sensors for enabling interactions between physical objects and the digital world.

Telematics Systems:

- Ivankova et al. (2020) includes telematics systems for vehicle tracking in logistics.

Automated Guided Vehicles (AGVs) / Autonomous Mobile Robots (AMRs):

- Ben-Daya et al. (2017) briefly discusses AGVs in supply chain automation.
- Khan et al. (2022) covers automation as part of Industry 4.0 and smart manufacturing.

Connected Wearables:

- Lee et al. (2015) mentions connected wearables such as Disney's MagicBand in enterprise applications.
- Macaulay et al. (2015) discusses connected wearables in logistics, specifically for tracking and monitoring.

IoT-enabled Smart Shelves:

- Hassan et al. (2020) focuses on smart shelves using IoT to track inventory in real-time.
- Macaulay et al. (2015) discusses the use of IoT in warehousing, which includes smart shelves.

IoT-based Predictive Maintenance Tools:

- Ben-Daya et al. (2017) covers predictive maintenance with IoT technologies.
- Lee et al. (2015) mentions predictive maintenance, particularly in industrial applications.
- Kern (2021) discusses the implementation of predictive maintenance as part of logistics digitalization.
- Miorandi et al. (2012) includes IoT-based predictive maintenance as part of the vision for IoT.

Middleware:

- Lee et al. (2015) discusses middleware as a key IoT technology that facilitates the integration of different systems and supports the development of IoT applications.
- Song et al. (2021) also addresses middleware as an enabling technology for IoT in smart logistics.

Cloud Computing:

- Lee et al. (2015) mentions cloud computing as an essential IoT technology for handling large amounts of data generated by IoT devices.
- Hammoudi et al. (2018) refers to cloud computing as a key infrastructure enabling IoT applications.
- Tang (2020) discusses the role of cloud computing in smart logistics systems.

References Addressing These Technologies Generally:

- Fernie & Sparks (2021) provides a broad overview of logistics and supply chain management but does not specifically address the listed IoT technologies.

- Silkina & Scherbakov (2019) focuses on logistics of smart supply chains without addressing specific IoT technologies like RFID, GPS, or smart sensors.

- Whitmore et al. (2015) explores IoT and Big Data in logistics but does not directly reference specific IoT technologies such as RFID, GPS, or smart sensors.

- Witkowski (2017) discusses innovative solutions in logistics like IoT and Big Data, with a focus on Industry 4.0 but without specific reference to technologies like connected wearables or smart shelves.

A.1: Research papers addressing each IoT technology in logistics

This section includes **Table A.2**, which maps research papers to the specific IoT technologies they address in the context of logistics. It highlights how different research studies focus on various IoT technologies and their applications in the logistics sector.

Table A. 2: Research Papers Addressing Each IoT Technology in Logistics

IoT Technology	Ben-Daya et al. (2017)	Hammoudi et al. (2018)	Hassan et al. (2020)	Ivankova et al. (2020)	Kern (2021)	Khan et al. (2022)	Lee et al. (2015)	Macaulay et al. (2015)	Miorandi et al. (2012)	Song et al. (2021)	Tang (2020)
RFID	Yes	Yes	Yes	No	No	No	Yes	No	Yes	Yes	No
GPS	Yes	Yes	No	Yes	No	No	No	No	No	No	No
Smart Sensors / WSN	Yes	No	No	No	Yes	No	Yes	No	Yes	Yes	No
Telematics Systems	No	No	No	Yes	No	No	No	No	No	No	No
AGVs / AMRs	Yes	No	No	No	No	Yes	No	No	No	No	No
Connected Wearables	No	No	No	No	No	No	Yes	Yes	No	No	No
Smart Shelves	No	No	Yes	No	No	No	No	Yes	No	No	No
Predictive Maintenance Tools	Yes	No	No	No	Yes	No	Yes	No	Yes	No	No
Middleware	No	No	No	No	No	No	Yes	No	No	Yes	No
Cloud Computing	No	Yes	No	No	No	No	Yes	No	No	No	Yes

A.2: IoT technologies descriptions and use cases in logistics

This section describes the core IoT technologies employed in logistics, highlighting their functionalities and specific use cases. It outlines how each technology is applied to improve logistics operations, such as real-time tracking, automation, and data management.

1. RFID (Radio Frequency Identification)

Description: RFID utilizes electromagnetic fields to automatically identify and track tags attached to various objects. These tags store data electronically and can be read by RFID readers from a distance, eliminating the need for physical contact and making asset monitoring more efficient (Ben-Daya et al., 2017; Hammoudi et al., 2018; Hassan et al., 2020; Lee et al., 2015; Miorandi et al., 2012; Song et al., 2021).

Use Case: In logistics, RFID is commonly used for managing inventories and tracking shipments. By tagging products, pallets, or containers with RFID, logistics providers can seamlessly monitor the movement of goods through warehouses, distribution centers, and delivery networks. This technology enhances speed and accuracy in identifying and sorting products, especially in high-traffic facilities, reducing manual intervention and operational delays (Ben-Daya et al., 2017; Hammoudi et al., 2018; Hassan et al., 2020; Lee et al., 2015; Song et al., 2021).

2. GPS (Global Positioning System)

Description: GPS is a satellite navigation system that offers real-time data on location and timing for GPS-enabled devices, allowing for continuous tracking of shipments, vehicle fleets, and assets in transit (Ben-Daya et al., 2017; Ivankova et al., 2020).

Use Case: GPS technology is heavily used in logistics to track delivery vehicles and monitor the movement of shipments. Companies like FedEx and DHL rely on GPS to ensure that delivery routes are optimized, that shipments reach their destinations on time, and that real-time updates can be provided to customers (Ben-Daya et al., 2017; Ivankova et al., 2020).

3. Smart Sensors/WSN (Wireless Sensor Networks)

Description: Smart sensors are devices capable of collecting and transmitting data related to environmental conditions such as temperature, humidity, or light. These sensors play an essential role in ensuring the safe transit of sensitive goods such as perishable items and pharmaceuticals. Wireless Sensor Networks (WSN) are composed of spatially distributed sensors (Ben-Daya et al., 2017; Hammoudi et al., 2018; Hassan et al., 2020; Lee et al., 2015; Miorandi et al., 2012; Song et al., 2021).

Use Case: In logistics, smart sensors and WSN are commonly employed to monitor temperature-sensitive shipments in cold chain logistics. Sensors placed in vehicles or cargo containers provide real-time updates on temperature changes, ensuring that goods remain within specified conditions during transit (Ben-Daya et al., 2017; Lee et al., 2015; Song et al., 2021).

4. Telematics Systems

Description: Telematics combines GPS tracking with on-board diagnostic tools to collect real-time data on vehicle performance, driving behavior, and fleet management. This provides logistics companies with actionable insights into vehicle usage, speed, fuel consumption, and maintenance requirements (Ivankova, 2020).

Use Case: In the logistics industry, telematics systems help optimize fleet management by tracking vehicle movements and driver behavior. These systems enable logistics providers to monitor vehicle routes, fuel usage, and delivery schedules in real-time, as well as to address maintenance needs before issues escalate (Ivankova, 2020).

5. Automated Guided Vehicles (AGVs)/Autonomous Mobile Robots (AMRs)

Description: These can both be considered a form of self-driving forklifts. AGVs (Automated Guided Vehicles) follow predefined paths using markers or wires, making them ideal for repetitive tasks in structured environments such as warehouses. In contrast, AMRs (Autonomous Mobile Robots) have more advanced navigation capabilities, using sensors and cameras to independently navigate dynamic, unstructured environments. This allows AMRs to adjust routes in real time, offering greater flexibility in operations. These technologies reduce the need for human involvement in routine transportation tasks (Ben-Daya et al., 2017; Khan et al., 2022).

Use Case: AGVs and AMRs are widely used in logistics operations to transport goods within warehouses, moving items between storage areas and packing stations. For instance, AGVs handle heavy pallets, while AMRs are used for more dynamic tasks like picking orders in fulfillment centers (Ben-Daya et al., 2017; Khan et al., 2022).

6. Connected Wearables (e.g., Smart Glasses, Wristbands)

Description: Connected wearables, such as smart glasses and wristbands, are IoT-enabled devices worn by employees. They collect data on worker activities, health, and environmental factors, improving both productivity and safety (Ben-Daya et al., 2017; Lee et al., 2015; Macaulay et al., 2015).

Use Case: Smart glasses are used in logistics for hands-free operations, such as order picking, where real-time instructions guide workers through the process. Wristbands are employed to monitor employee health and safety, particularly in environments that involve strenuous physical labor or potential hazards (Ben-Daya et al., 2017; Macaulay et al., 2015).

7. IoT-enabled Smart Shelves*

Description: Smart shelves are equipped with sensors that can detect the presence of items, transmitting real-time data on stock levels. This technology helps businesses maintain optimal inventory levels and automate restocking processes (Hassan et al., 2020).

Use Case: In both logistics and retail environments, smart shelves monitor stock levels and trigger automatic restocking when supplies fall below a specified threshold. For instance, when an item is removed, the system sends an alert to the inventory management system to replenish stock levels, improving inventory accuracy (Hassan et al., 2020).

**Note: There are limited academic sources on smart shelves as it remains an emerging technology in logistics.*

8. IoT-based Predictive Maintenance Tools

Description: These tools rely on sensors embedded in equipment to monitor performance and detect early signs of wear or malfunction, allowing companies to perform maintenance before a breakdown occurs (Ben-Daya et al., 2017; Ivankova et al., 2020; Kern, 2021; Lee et al., 2015; Miorandi et al., 2012).

Use Case: Predictive maintenance tools are used in logistics to monitor the condition of vehicles and warehouse equipment. By analyzing data from these sensors, logistics companies can perform timely maintenance, preventing operational interruptions and minimizing downtime (Ben-Daya et al., 2017; Ivankova et al., 2020; Kern, 2021).

9. Middleware

Description: Middleware is software that serves as a bridge between different systems, devices, and applications in an IoT environment, facilitating data exchange and communication between them. It allows heterogeneous IoT devices to communicate seamlessly, ensuring interoperability and smooth operation within complex systems (Lee et al., 2015; Song et al., 2021).

Use Case: In logistics, middleware is used to connect various IoT devices, such as sensors, RFID tags, and smart shelves, with enterprise resource planning (ERP) systems and warehouse management systems (WMS). This enables real-time data flow between these devices and backend systems, providing comprehensive visibility into operations, improving decision-making, and streamlining logistics processes (Lee et al., 2015; Song et al., 2021).

10. Cloud Computing

Description: Cloud computing provides on-demand access to computing resources such as data storage, processing power, and software applications over the internet. It enables the collection, storage, and analysis of vast amounts of data generated by IoT devices, offering scalability, flexibility, and real-time processing capabilities (Hammoudi et al., 2018; Lee et al., 2015; Tang, 2020).

Use Case: In logistics, cloud computing is used to store and process data from IoT-enabled devices like GPS trackers, RFID systems, and smart sensors. Logistics companies rely on the Cloud to manage supply chain data, optimize routing, track shipments, and improve customer service through real-time updates and predictive analytics. Cloud-based platforms also enable seamless collaboration between supply chain partners, enhancing overall operational efficiency (Lee et al., 2015; Tang, 2020).

A.3: IoT technologies benefits in logistics (shortlist)

This section identifies the primary benefits of IoT technologies in logistics, including enhanced operational efficiency, improved tracking, and automation. **Table A.3** further maps these benefits to the corresponding IoT technologies, offering a concise view of their contributions to the logistics industry.

1. RFID (Radio Frequency Identification) benefits:

   (B10) Improved inventory visibility and accuracy (Ben-Daya et al., 2017; Lee et al., 2015).
   (B1) (B4) Real-time tracking enhances resource management (Ben-Daya et al., 2017; Hassan et al., 2020).
   (B3) (B2) Automation of stocktaking and asset tracking reduces labor costs and improves operational efficiency (Ben-Daya et al., 2017; Miorandi et al., 2012).

2. GPS (Global Positioning System) benefits:

   (B1) (B4) Real-time tracking of shipments and vehicles (Ben-Daya et al., 2017; Ivankova et al., 2020).
   (B7) Route optimization reduces fuel consumption (Ivankova et al., 2020).
   (B1) Improved customer service through accurate delivery updates (Ivankova et al., 2020).

3. Smart Sensors / WSN (Wireless Sensor Networks) benefits:

   (B1) Real-time monitoring of environmental conditions (e.g., temperature, humidity) (Ben-Daya et al., 2017; Song et al., 2021).
   (B2) Immediate corrective actions to maintain product quality (Ben-Daya et al., 2017; Song et al., 2021).
   (B2) Improved operational efficiency by reducing waste and ensuring product safety (Ben-Daya et al., 2017)

4. Telematics Systems benefits:

   (B7) Improved fuel efficiency and route optimization (Ben-Daya et al., 2017; Ivankova et al., 2020).
   (B1) (B5) Real-time fleet monitoring for enhanced safety and performance (Ivankova et al., 2020).
   (B6) Predictive maintenance reduces breakdowns (Ivankova et al., 2020).

5. Automated Guided Vehicles (AGVs) / Autonomous Mobile Robots (AMRs) benefits:

   (B3) Automating material handling reduces labor costs and human error (Ben-Daya et al., 2017).
   (B2) AGVs for constant productivity of repetitive tasks, AMRs for dynamic environments (Khan et al., 2022).
   (B5) Improved workplace safety by reducing human interaction with heavy loads (Ben-Daya et al., 2017).

6. Connected Wearables (e.g., Smart Glasses, Wristbands) benefits:

   (B2) Hands-free operations improve productivity (e.g., order picking) (Lee et al., 2015; Macaulay et al., 2015).
   (B5) Worker health and safety monitoring reduces injuries (Lee et al., 2015; Macaulay et al., 2015).

7. IoT-enabled Smart Shelves benefits:

   (B10) (B3) (B1) Inventory accuracy and automated restocking based on real-time stock levels (Hassan et al., 2020).
   (B3) Reduced manual labor for stock checks (Hassan et al., 2020).

8. IoT-based Predictive Maintenance Tools benefits:

   (B6) (B2) Proactive maintenance reduces downtime and extends equipment life (Ben-Daya et al., 2017).
   (B4) Improved asset utilization by preventing breakdowns (Ben-Daya et al., 2017; Kern, 2021).

9. Middleware benefits:

(B9) Seamless integration of IoT devices with enterprise systems (ERP, WMS) (Lee et al., 2015; Song et al., 2021).
(B1) Real-time data flow improves visibility into logistics operations (Song et al., 2021).

10. Cloud Computing benefits:

(B8) On-demand access to scalable data storage and processing resources (Lee et al., 2015; Tang, 2020).
(B1) Improved collaboration between supply chain partners through real-time data sharing (Tang, 2020).

Table A. 3: Benefits from IoT Technology in Logistics Mapping

Benefits	RFID	GPS	WSN	Telematics	AGV/AMR	Wearables	Smart Shelves	Predictive Maint.	Middleware	Cloud Comp.
(B1) Real-time tracking/monitoring	✓	✓	✓	✓			✓		✓	✓
(B2) Improved operational efficiency	✓		✓		✓	✓		✓		
(B3) Automation for reduced labor costs	✓				✓		✓			
(B4) Enhanced resource management	✓	✓						✓		
(B5) Improved safety				✓	✓	✓				
(B6) Proactive maintenance				✓				✓		
(B7) Route/fuel optimization		✓		✓						
(B8) Data Storage and Processing										✓
(B9) Seamless integration of devices									✓	
(B10) Increased inventory accuracy	✓						✓			

A.4: IoT technologies challenges (shortlist)

This section highlights the major challenges faced in the implementation of IoT technologies in logistics. It presents a short list of these challenges, as drawn from the research studies. **Table A.4** maps these challenges to the specific IoT technologies, providing insight into the potential obstacles for each technology.

1. RFID (Radio Frequency Identification) **c**hallenges:

   (C4) Integration with legacy systems is costly and complex (Ben-Daya et al., 2017).
   (C9) Initial infrastructure costs (installation of RFID readers, hardware) (Ben-Daya et al., 2017).
   (C2) Data management issues related to handling large volumes of real-time data (Ben-Daya et al., 2017).
   (C7) (C8) User acceptance and training barriers (Miorandi et al., 2012).
   (C6) Interference Issues: RFID signals can be disrupted by metals or liquids (Hammoudi et al., 2018).
   (C5) Scalability: Expanding RFID systems across locations can pose infrastructure challenges (Song et al., 2021).

2. GPS (Global Positioning System) **c**hallenges:

   (C9) High implementation costs for fleet-wide systems (Ben-Daya et al., 2017).
   (C6) Signal issues in remote or obstructed areas (Ivankova et al., 2020).
   (C2) Data management and storage strain IT systems (Ivankova et al., 2020).
   (C3) Privacy Concerns: GPS tracking raises privacy concerns for employee monitoring (Ben-Daya et al., 2017).

3. Smart Sensors / **WSN (Wireless Sensor Networks) c**hallenges:

   (C2) Data management issues, particularly large volumes of sensor data (Ben-Daya et al., 2017; Miorandi et al., 2012).
   (C10) (C11) Installation and maintenance costs for large-scale networks (Ben-Daya et al., 2017).
   (C5) Power Consumption: Managing energy efficiency for large networks of sensors is challenging (Miorandi et al., 2012).
   (C6) Wireless Interference: WSN may face interference from other wireless devices (Hammoudi et al., 2018).

4. Telematics Systems **c**hallenges:

   (C9) High upfront costs for hardware installation (Ivankova et al., 2020).
   (C4) (C1) Integration complexity with existing fleet management systems (Ivankova et al., 2020).
   (C2) Data management challenges due to large volumes of data collected (Ivankova et al., 2020).
   (C3) Data Privacy: Telematics data collection raises privacy concerns, particularly around driver behavior (Ivankova et al., 2020).

5. Automated Guided Vehicles (AGVs) / Autonomous Mobile Robots (AMRs) **c**hallenges:

   (C9) High capital investment for system integration (Ben-Daya et al., 2017).
   (C1) (C4) (C5) Technical complexity in AMRs for dynamic environments (Khan et al., 2022).
   (C11) Ongoing maintenance costs and new potential safety hazards (Ben-Daya et al., 2017).
   (C1) (C4) System Integration: Integrating AGVs/AMRs with existing warehouse systems can be complex (Khan et al., 2022).
   (C7) Employee Resistance: Workers may resist due to concerns about job displacement (Ben-Daya et al., 2017).

6. Connected Wearables (e.g., Smart Glasses, Wristbands) **c**hallenges:

   (C3) Data security and privacy concerns, especially for health data (Lee et al., 2015).
   (C9) (C8) Initial investment and training requirements for workers (Macaulay et al., 2015).

(C6) Battery Life: Wearables have limited battery life, impacting productivity (Lee et al., 2015).
(C7) Employee Acceptance: Workers may resist wearables due to discomfort or privacy concerns (Macaulay et al., 2015).

7. IoT-enabled Smart Shelves **c**hallenges:

(C9) High implementation costs for sensors and data systems (Hassan et al., 2020).
(C4) Complex integration into existing warehouse management systems (Hassan et al., 2020).
(C6) Ensuring real-time accuracy of sensors can be challenging (Hassan et al., 2020).
(C2) Managing large volumes of data generated by smart shelves can overwhelm systems (Macaulay et al., 2015).

8. IoT-based Predictive Maintenance Tools **c**hallenges:

(C9) Cost of sensors and infrastructure for monitoring equipment (Ben-Daya et al., 2017).
(C2) **(C4)** Data management and integration challenges with existing systems (Lee et al., 2015).
(C7) Maintenance teams may resist new workflows introduced by predictive tools (Ben-Daya et al., 2017).
(C11) Ongoing costs for monitoring and training staff can be high (Ben-Daya et al., 2017).

9. Middleware **c**hallenges:

(C1) **(C4)** Interoperability issues between IoT devices and legacy systems can complicate integration (Lee et al., 2015).
(C9) Middleware often requires expensive customization to integrate with logistics systems (Song et al., 2021).

10. Cloud Computing **c**hallenges:

(C3) Data security concerns related to storing sensitive information in the cloud (Lee et al., 2015; Hammoudi et al., 2018).
(C3) Regulatory compliance issues, such as GDPR, in managing data (Hammoudi et al., 2018).
(C6) Cloud services are vulnerable to service interruptions, which can disrupt logistics (Tang, 2020).
(C10) Vendor Lock-In: Relying on a specific cloud provider can make switching costly (Hammoudi et al., 2018).

Table A. 4: Challenges for IoT Technology Mapping

Challenges	RFID	GPS	WSN	Telematics	AGV/AMR	Wearables	Smart Shelves	Predictive Maint.	Middleware	Cloud Comp.
(C1) Data Interoperability				✓	✓			✓	✓	
(C2) Data Management	✓	✓	✓	✓			✓	✓		
(C3) Data Security and Privacy		✓		✓		✓				✓
(C4) Integration with IT Infrastructure	✓			✓	✓		✓	✓	✓	
(C5) Scalability and Maintenance	✓		✓		✓					
(C6) Environmental/ Operational Limitations	✓	✓	✓		✓	✓	✓			✓
(C7) Change Management	✓				✓	✓		✓		
(C8) Employee Readiness	✓				✓	✓				✓
(C9) High Initial Investment	✓	✓	✓	✓	✓	✓	✓	✓	✓	
(C10) High Implementation Costs			✓							✓
(C11) High Maintenance Costs			✓		✓			✓		

A.5: Challenges Categorization

This section presents a categorized view of the challenges associated with IoT technology adoption in logistics. **Table A.5** organizes these challenges into broader categories, helping to understand the common themes and areas of concern across different technologies.

Table A. 5: Challenges Categorization

Challenge Category	**Challenge**
Technical	**(C1)** Data Interoperability **(C2)** Data Management **(C3)** Data Security and Privacy **(C4)** Integration with IT Infrastructure **(C5)** Scalability and Maintenance **(C6)** Environmental/ Operational Limitations
Organizational	**(C7)** Change Management **(C8)** Employee Readiness
Financial	**(C9)** High Initial Investment **(C10)** High Implementation Costs **(C11)** High Maintenance Costs

A.6: Challenges Identified from General IoT in Logistics Papers

This section outlines the challenges identified from general IoT research papers that focus on the logistics sector, but not one IoT technology in particular. **Table A.6** lists these challenges, offering a broader perspective on the difficulties that arise in IoT implementation beyond specific technologies.

Table A. 6: Challenges Identified from General IoT in Logistics Papers

Research Paper	Challenge	Descriptive Summary
Fernie & Sparks (2021)	**(C1)** Data Interoperability **(C2)** Data Management **(C5)** Scalability and Maintenance **NEW - (C12)** Culture of Innovation	Data Interoperability: Discusses integration challenges in logistics, particularly as systems need to communicate seamlessly. Data Management: Highlights issues around managing and processing the growing amounts of data generated by supply chain activities. Scalability and Maintenance: Points out difficulties in scaling logistics operations and maintaining systems in a highly connected environment. Culture of Innovation: Emphasizes the necessity of fostering innovation to keep up with the evolving landscape of logistics and supply chain management, pushing organizations to adopt new technologies and methodologies.
Silkina & Scherbakov (2019)	**(C7)** Change Management **(C8)** Employee Readiness **NEW - (C12)** Culture of Innovation	Change Management: Examines the challenges of transitioning to smarter supply chain systems, where organizations often face resistance to change. Employee Readiness: Emphasizes that employees must be adequately trained and prepared to adapt to technological advancements in logistics. Culture of Innovation: Discusses the need for organizations to cultivate a mindset that encourages innovation, allowing businesses to remain competitive by continuously adopting digital technologies and embracing smarter supply chain systems.
Witkowski (2017)	**(C1)** Data Interoperability **(C3)** Data Security and Privacy **(C5)** Scalability and Maintenance **NEW - (C12)** Culture of Innovation **NEW - (C13)** Difficult ROI	Data Interoperability: Highlights the complexity of integrating data from multiple sources, especially in the context of Industry 4.0 and IoT ecosystems. Data Security and Privacy: Discusses concerns about securing sensitive data and the risk of breaches as IoT technologies generate and transfer large amounts of data. Scalability and Maintenance: Notes how scaling IoT systems across logistics operations can lead to challenges in system maintenance and ongoing support. Culture of Innovation: Suggests that the drive for innovation in logistics is a critical factor in adopting technologies like IoT and Big Data, but organizations must overcome cultural inertia to fully embrace digital transformation. Difficult ROI: Emphasizes the difficulty in calculating ROI for IoT implementations in logistics, given that benefits like efficiency gains and improved transparency may not immediately translate into measurable financial returns.
Whitmore et al. (2014)	**(C1)** Data Interoperability **(C2)** Data Management **(C3)** Data Security and Privacy **(C5)** Scalability and Maintenance **NEW - (C13)** Difficult ROI	Data Interoperability: Describes the challenge of integrating various IoT systems across logistics networks. Data Management: Notes the growing difficulty of handling the large amounts of real-time data generated by IoT devices. Data Security and Privacy: Highlights concerns about the security of data generated by IoT systems, particularly regarding unauthorized access and privacy risks. Scalability and Maintenance: Describes the difficulty in scaling IoT systems within logistics operations, particularly when it comes to maintaining these systems over time. Difficult ROI: Discusses the uncertainty around quantifying the return on investment for IoT technologies in logistics, as many of the long-term benefits (like operational efficiency and supply chain visibility) are hard to measure in financial terms.

A.7: Challenges categorization updated – general IoT in logistics papers

Following the insights gained from general IoT in logistics papers, this section provides an updated categorization of challenges. **Table A.7** shows the revised categorization based on additional challenges identified from broader IoT literature, ensuring a comprehensive view of potential obstacles.

Table A. 7: Challenges Categorization Updated after General IoT in Logistics Papers

Challenge Category	Challenge
Technical	**(C1)** Data Interoperability **(C2)** Data Management **(C3)** Data Security and Privacy **(C4)** Integration with IT Infrastructure **(C5)** Scalability and Maintenance **(C6)** Environmental/ Operational Limitations
Organizational	**(C7)** Change Management **(C8)** Employee Readiness **(C12)** Culture of Innovation
Financial	**(C9)** High Initial Investment **(C10)** High Implementation Costs **(C11)** High Maintenance Costs **(C13)** Difficult ROI

A.8: IoT technologies benefits for logistics and challenges descriptions

This section provides detailed descriptions of the benefits and challenges associated with IoT technologies in logistics. It delves into the advantages these technologies offer, as well as the barriers to their successful implementation, offering a holistic understanding of their impact on logistics operations. This section summarizes results from previous sections of **Appendix A**.

1. RFID (Radio Frequency Identification)

Benefits: RFID significantly boosts inventory visibility and accuracy, reducing the occurrence of errors and accelerating the sorting process. Its ability to track assets in real-time enhances resource management and overall supply chain efficiency by providing precise, up-to-date information on the movement of goods. RFID also automates essential tasks, such as stocktaking and asset tracking, leading to reductions in labor costs and improved operational efficiency (Ben-Daya et al., 2017; Hammoudi et al., 2018; Hassan et al., 2020; Lee et al., 2015; Miorandi et al., 2012; Song et al., 2021).

Challenges: A major challenge in adopting RFID technology is the integration with existing IT systems, and especially legacy infrastructure. This often demands significant investment to ensure compatibility and interoperability, which can be technically complex and resource-intensive (Ben-Daya et al., 2017). Large-scale deployment further requires infrastructure upgrades, including the installation of RFID readers and associated hardware, which can inflate both initial costs and ongoing maintenance expenses (Ben-Daya et al., 2017). Additionally, managing the large volumes of real-time data generated by RFID systems can strain the existing IT infrastructure, requiring robust data processing and storage capabilities, as well as new data security measures (Ben-Daya et al., 2017). Lastly, user acceptance of RFID technology can be a significant barrier. Employees may require additional training to operate the new technology (using RFID scanners, and removing the tags before final delivery to customers), and resistance to change can slow down the adoption process (Miorandi et al., 2012).

2. GPS (Global Positioning System)

Benefits: GPS technology plays a crucial role in providing real-time data on the location and movement of shipments and vehicles. This enables logistics companies to optimize delivery routes, reducing fuel consumption and improving delivery times. The enhanced visibility offered by GPS also leads to better customer service by providing accurate delivery updates and improving overall logistics coordination (Ivankova et al., 2020; Whitmore et al., 2015). The ability to monitor fleet movements in real time supports resource optimization and operational efficiency (Ben-Daya et al., 2017; Ivankova et al., 2020).

Challenges: While GPS provides significant benefits in real-time vehicle tracking and route optimization, its implementation can be costly, especially for large-scale operations that require widespread installation of tracking systems across a fleet (Ben-Daya et al., 2017). In addition, maintaining accurate GPS tracking in areas with poor signal coverage can disrupt operations, especially in remote or urban environments with physical obstructions (Ivankova et al., 2020). Managing and processing the large volumes of data generated by GPS systems can also strain existing IT infrastructure, requiring additional investment in data storage, analytics, and security measures (Ivankova et al., 2020).

3. Smart Sensors / WSN (Wireless Sensor Networks)

Benefits: Smart sensors provide real-time monitoring of environmental conditions such as temperature, humidity, and vibration, making them particularly valuable in cold chain logistics for perishable goods. By ensuring that products are stored and transported under optimal conditions, smart sensors help maintain product quality and safety. Their ability to collect and transmit data in real time allows for immediate corrective actions, which reduces waste and improves operational efficiency (Ben-Daya et al., 2017; Hammoudi et al., 2018; Hassan et al., 2020; Lee et al., 2015; Miorandi et al., 2012; Song et al., 2021).

Challenges: The integration of smart sensors into logistics networks presents several challenges, particularly around data management. The continuous stream of data generated by sensors, in higher volumes than RFID and GPS solutions, could easily overwhelm legacy IT systems if not properly managed, necessitating significant upgrades in data processing and safe storage capabilities (Ben-Daya et al., 2017). Additionally, the cost of installing and maintaining sensor networks, particularly in large-scale operations, can be prohibitive, especially when the infrastructure requires regular calibration and maintenance (Ben-Daya et al., 2017; Hammoudi et al., 2018; Miorandi et al., 2012).

4. Telematics Systems

Benefits: Telematics systems enable logistics companies to monitor vehicle usage, driving behavior, and fleet efficiency in real time. This data-driven approach improves fuel efficiency, enhances route optimization, and helps in identifying potential maintenance needs before breakdowns occur. By providing insights into fleet performance, telematics systems also contribute to increased safety and lower operational costs (Ivankova et al., 2020).

Challenges: Despite their advantages, telematics systems face barriers to widespread adoption, primarily due to the high upfront costs involved in equipping vehicles with the necessary hardware. The integration of telematics with existing fleet management software can also be complex, requiring significant customization and technical expertise. Furthermore, the sheer volume of data generated by telematics systems can also impact IT infrastructure, necessitating investments in data processing and storage solutions (Ivankova et al., 2020).

5. Automated Guided Vehicles (AGVs)/Autonomous Mobile Robots (AMRs)

Benefits: AGVs and AMRs play a key role in automating material handling within warehouses and distribution centers, reducing the need for human intervention. AGVs are particularly useful for repetitive tasks in structured environments, while AMRs offer greater flexibility by autonomously navigating dynamic, unstructured spaces. Both technologies enhance operational efficiency, lower labor costs, and improve workplace safety by reducing the risk of accidents (Ben-Daya et al., 2017; Khan et al., 2022).

Challenges: The adoption of AGVs and AMRs requires significant capital investment, especially when integrating these technologies into existing warehouse systems. Furthermore, the complexity of implementing AMRs in dynamic environments can pose technical challenges, particularly in terms of ensuring seamless navigation and task coordination. Additionally, ongoing maintenance costs for these automated systems can be substantial, further increasing the total cost of ownership (Ben-Daya et al., 2017; Khan et al., 2022). There are also health and safety concerns related to the operation of AGVs and AMRs in shared spaces, as the risk of collisions with other equipment or workers can present significant hazards if safety measures are not adequately implemented. Lastly, the potential reduction in labor due to automation may raise concerns about job displacement, contributing to resistance from employees and further complicating the adoption process (Ben-Daya et al., 2017; Khan et al., 2022).

6. Connected Wearables (e.g., Smart Glasses, Wristbands)

Benefits: Connected wearables, such as smart glasses and wristbands, offer hands-free tools for workers, improving both productivity and safety in logistics environments. These devices can provide real-time instructions, enhancing order-picking accuracy and speed. Additionally, wearables monitor worker health and safety conditions, reducing the risk of injury and promoting a healthier work environment (Lee et al., 2015; Macaulay et al., 2015).

Challenges: While wearables provide valuable benefits, their integration into logistics workflows is not without challenges either. Ensuring compatibility with existing IT systems and training workers to effectively use these new technologies can be time-consuming and costly. Data security and privacy concerns arise due to the sensitive nature of personal data collected by wearable devices, which may include health information and employee location tracking. Ensuring that this data is securely managed and compliant with data protection regulations adds another layer of complexity. Furthermore, the initial investment in wearables and their associated infrastructure can be prohibitive for smaller companies, limiting their widespread adoption (Lee et al., 2015; Macaulay et al., 2015).

7. IoT-enabled Smart Shelves*

Benefits: Smart shelves equipped with sensors can automatically detect stock levels, triggering restocking processes when inventory is low. This technology improves inventory accuracy, reduces stockouts, and helps optimize warehouse management by providing real-time data on product availability. In retail environments, smart shelves can significantly reduce manual labor associated with stock checks and improve supply chain responsiveness (Hassan et al., 2020; Macaulay et al., 2015).

Challenges: Despite the potential of smart shelves, their adoption is still limited due to high implementation costs, especially in large-scale operations. The need for reliable sensor technology and robust data management systems adds to the complexity and cost of deploying these systems. Smart shelves are an emerging technology, and further refinement and testing may be needed to fully integrate them into existing warehouse and inventory management systems (Hassan et al., 2020).

**Note: There are limited academic sources on smart shelves as it remains an emerging technology in logistics.*

8. IoT-based Predictive Maintenance Tools

Benefits: Predictive maintenance tools rely on IoT sensors embedded in equipment to monitor performance and detect signs of wear or malfunction. By analyzing this data, logistics companies can perform timely maintenance, reducing downtime and preventing costly breakdowns. This proactive approach helps improve asset utilization and extends the lifespan of critical machinery (Ben-Daya et al., 2017; Ivankova et al., 2020; Kern, 2021; Miorandi et al., 2012).

Challenges: The primary challenge in adopting predictive maintenance tools is the cost of equipping machinery with the necessary sensors and supporting infrastructure. Additionally, predictive maintenance systems generate large amounts of data, which requires secure storage, advanced analytics, and IT capabilities to process and interpret effectively. As with other IoT technologies, integrating predictive maintenance tools into existing systems can be complex and may require significant technical expertise (Ben-Daya et al., 2017; Kern, 2021). Furthermore, post-implementation monitoring is essential to ensure the continued effectiveness of the system, which may necessitate new roles, such as monitoring teams, dedicated to analyzing data and coordinating maintenance actions. Organizational changes, including training programs for maintenance teams and adapting workflows to incorporate predictive insights, can also pose challenges, as staff need to adjust to new responsibilities and processes (Ben-Daya et al., 2017; Kern, 2021).

9. Middleware

Benefits: Middleware plays a crucial role in integrating diverse IoT devices and systems within logistics networks. By facilitating seamless communication between IoT devices such as sensors, RFID tags, and enterprise systems like ERP and WMS, middleware ensures real-time data flow across various platforms. This integration allows companies to gain complete visibility into logistics operations, improving decision-making and resource management. Middleware also helps streamline processes by ensuring that devices across different platforms work together without compatibility issues, resulting in enhanced operational efficiency (Lee et al., 2015; Song et al., 2021).

Challenges: The primary challenge in implementing middleware lies in ensuring compatibility across a wide range of IoT devices and legacy systems. This often requires significant investment in software and hardware upgrades, as well as custom configurations to handle diverse communication protocols. Additionally, managing the real-time data flow facilitated by middleware can strain IT infrastructure, especially in terms of data processing and storage. Security is another concern, as middleware facilitates data exchange between multiple systems, increasing the risk of cyberattacks and data breaches if proper safeguards are not in place (Lee et al., 2015; Song et al., 2021).

10. Cloud Computing

Benefits: Cloud computing offers logistics companies the ability to scale their data storage and processing capabilities on demand, without the need for extensive on-site infrastructure. By leveraging the cloud, companies can store and process vast amounts of real-time data generated by IoT devices, such as sensors, GPS trackers, and RFID systems.

Cloud platforms also enable real-time collaboration and data sharing between supply chain partners, improving transparency and coordination across the logistics network, which enhances overall performance (Hammoudi et al., 2018; Lee et al., 2015; Tang, 2020).

Challenges: While cloud computing provides significant advantages, its adoption in logistics presents challenges. The cost of cloud services, particularly for large-scale operations, can be substantial. Storing sensitive logistics data in the cloud introduces data security risks, including unauthorized access and compliance with data protection regulations. Additionally, integrating cloud platforms with existing IT infrastructure can be technically complex, requiring specialized expertise and significant resources. Potential downtime or service disruptions in cloud services can also impact logistics operations, creating potential bottlenecks (Lee et al., 2015; Tang, 2020).

B

REQUIREMENTS ANALYSIS

This appendix provides a detailed analysis of the research papers and theoretical models that inform the development of the IoT adoption framework in logistics. The requirements derived from this analysis guide the framework's structure, ensuring that it addresses the multifaceted challenges of IoT implementation.

B.1: Summary of Key Research Studies

This section provides a brief summary of each research paper from **Appendix A,** presenting the key findings from the research papers used to analyze IoT adoption in logistics. Each reference is mapped to the challenges that inform the framework requirements in **Table B.1**.

Table B. 1: Summary of Key Research Studies

Author(s) & Year	Paper Title	Key Insights	Challenges Addressed
Ben-Daya et al. (2017)	Internet of Things in supply chain	Discusses integration of IoT in supply chains, focusing on technical readiness, financial investment, and organizational challenges	Data management, high investment, system integration, organizational challenges, scalability
Lee et al. (2015)	The Internet of Things—A new industrial revolution	Highlights the importance of readiness in financial, organizational, and technical aspects during IoT adoption	Data security, system integration, scalability, data management
Miorandi et al. (2012)	Internet of Things: Vision, applications, and research challenges	Focuses on the technical and organizational challenges of IoT adoption in logistics systems	User acceptance, data management, operational challenges, scalability
Macaulay et al. (2015)	The Internet of Things in logistics	Explores employee readiness and organizational change as key factors in the successful deployment of IoT technologies	Data security, employee resistance, system integration, investment
Song et al. (2021)	IoT applications in smart logistics	Stresses the phased approach to IoT adoption and the role of leadership in overcoming barriers	System integration, scalability, technical complexity

B.2: Mapping of Research Papers to Requirements

Table B.2 illustrates how the insights from the analyzed literature informed the development of each requirement. It maps each requirement to the specific research papers and explains the connection between the challenges highlighted by the authors and the formulated framework requirements.

Table B. 2: Mapping of Research Papers to Requirements

Requirement No.	Requirement Description	Supporting References	Key Insights from Literature
B.2.1	The framework must integrate technical, organizational, and financial aspects to tackle the multifaceted nature of IoT adoption.	Ben-Daya et al. (2017); Lee et al. (2015); Song et al. (2021)	The integration of these three dimensions ensures that logistical IoT implementation addresses the interconnected challenges.
B.2.2	The framework must assess technical, organizational, and financial readiness at early stages.	Ben-Daya et al. (2017); Lee et al. (2015)	The early assessment of readiness helps mitigate risks related to financial investment and technical constraints.
B.2.3	The framework could build awareness around IoT benefits by sharing success stories.	Ben-Daya et al. (2017); Song et al. (2021)	Raising awareness about the benefits of IoT adoption encourages stakeholders to engage in and support the initiative.
B.2.4	The framework should foster leadership support.	Macaulay et al. (2015); Song et al. (2021)	Organizational leadership is critical in driving the adoption process and mitigating resistance from employees.
B.2.5	The framework should clearly communicate the vision to align stakeholders.	Miorandi et al. (2012); Lee et al. (2015)	Clear communication ensures stakeholder alignment and support for IoT initiatives, reducing internal resistance.
B.2.6	The framework could include early user training.	Macaulay et al. (2015); Miorandi et al. (2012)	User training helps reduce resistance by preparing employees to handle new IoT technologies, facilitating smoother adoption.
B.2.7	The framework must deploy IoT in phases.	Ben-Daya et al. (2017); Song et al. (2021)	Phased deployment allows organizations to manage costs and risks while testing the effectiveness of IoT technologies.
B.2.8	The framework must assess the implementation process's impact on operations.	Lee et al. (2015); Ben-Daya et al. (2017)	Monitoring the impact on operations helps identify any disruptions or inefficiencies during IoT implementation.
B.2.9	The framework must assess the company's technical capabilities.	Ben-Daya et al. (2017); Lee et al. (2015)	Assessing technical capabilities ensures the organization has the necessary infrastructure to support IoT technologies.
B.2.10	The framework must assess company financial capability.	Ben-Daya et al. (2017); Song et al. (2021)	Evaluating financial readiness helps ensure the organization can sustain the costs of implementing IoT technologies.

B.3: Technology Adoption Models and Their Insights

Table B.3 provides a structured analysis of the key technology adoption models used to derive requirements for the IoT framework designed in Chapter 4. These models, previously used and addressed in the TU Delft CoSEM curriculum, have been used to develop additional requirements that complement the insights obtained from the literature review, further shaping the overall IoT adoption framework.

Table B. 3: Mapping of Research Papers to Requirements

Model	Key Insights	Challenges Addressed
Technology Readiness Index (TRI)	TRI focuses on assessing the readiness of organizations and individuals to adopt new technologies. Readiness levels vary based on the technological, organizational, and financial aspects.	Readiness for IoT implementation, technical and organizational challenges.
Technology-Organization-Environment (TOE)	TOE highlights the influence of external environments, internal organizational readiness, and technological capabilities in technology adoption.	Organizational and environmental readiness, technical availability.
Innovation Diffusion Theory (IDT)	IDT emphasizes how innovations spread over time, particularly through phases of early adopters, pilots, and demonstrations. Success stories accelerate the adoption of new technologies.	Adoption timing, gradual implementation, early adopter engagement.
Lewin's Change Management Model	Lewin's model identifies the unfreezing, change, and refreezing phases as critical to facilitating organizational change and technology adoption. User training and feedback mechanisms are essential.	Employee resistance, change management, flexibility, and adaptability.
ADKAR Model	The ADKAR model emphasizes the importance of leadership support and communication in guiding employees through organizational change. Employee training is central to successful adoption.	Employee resistance, leadership engagement, clear communication of vision.
Kotter's 8-Step Change Model	Kotter's model stresses building leadership support, communicating a clear vision, and using phased approaches to adoption to minimize resistance and uncertainty.	Leadership support, phased implementation, stakeholder alignment.
Resource-Based View (RBV)	RBV highlights the importance of leveraging existing resources and capabilities within an organization to implement new technologies effectively.	Leveraging resources, minimizing operational disruption, measuring performance.
Dynamic Capabilities Framework	This framework focuses on the ability of organizations to reconfigure internal and external competencies in response to rapidly changing environments.	Flexibility, adaptability, integration of various dimensions (technical, organizational, financial).
Unified Theory of Acceptance and Use of Technology (UTAUT)	UTAUT identifies how user training, perceived ease of use, and perceived usefulness impact technology adoption. Employee training and assessing operational impact are crucial.	Employee training, operational impact assessment.
Technology Acceptance Model (TAM)	TAM focuses on user acceptance of technology based on its perceived ease of use and usefulness. Pilot programs and early user engagement help reduce resistance to change.	Employee training, pilot programs, demonstrations.
Cooper's Stage-Gate Process	Cooper's Stage-Gate Process (1990) defines a structured process for product innovation, guiding projects through distinct stages separated by decision points (gates). The model emphasizes the need for clear planning, resource allocation, and evaluation at each stage.	Clear decision-making checkpoints, risk management, thorough implementation planning.

B.4: Requirements Derived from Technology Adoption Models

In this section, **Table B.4** illustrates how insights from the analyzed technology adoption models informed the development of each requirement. It maps each requirement to the specific models and explains the connection between the key principles from these models and the formulated framework requirements.

Table B. 4: Requirements Derived from Technology Adoption Models

Requirement No.	Requirement Description	Supporting Models	Key Insights from Models
B.4.1	The framework must specify a stage-gate process needed to navigate the framework.	Cooper (1990); Kotter's 8-Step Change Model; Lewin's Change Management Model	Stage-gate processes ensure that decisions are made at key checkpoints, allowing structured progression through IoT adoption phases.
B.4.2	The framework must build on the work of other authors and established frameworks.	TOE Framework; Resource-Based View (RBV); Dynamic Capabilities Framework	By building on established frameworks, the framework benefits from validated best practices and academic insights, ensuring that the IoT adoption is both practical and grounded in existing research.
B.4.3	The framework must integrate technical, and organizational aspects to tackle the multifaceted nature of IoT adoption.	TOE Framework; Dynamic Capabilities Framework; Resource-Based View (RBV)	Integration of different aspects (technical and organizational) ensures a comprehensive and adaptable approach to IoT adoption that addresses the multidimensional nature of technology integration.
B.4.4	The framework must assess technical, organizational readiness at early stages.	Technology Readiness Index (TRI); TOE Framework; Dynamic Capabilities Framework	Early-stage readiness assessment ensures that potential barriers (technical and organizational) are identified and addressed before full-scale IoT implementation.
B.4.5	The framework could build awareness around IoT benefits by sharing success stories.	IDT; Technology Acceptance Model (TAM); UTAUT	Sharing success stories helps promote IoT adoption by showcasing real-world examples of how the technologies have improved operational efficiency and driven innovation in logistics.
B.4.6	The framework should foster leadership support.	Kotter's 8-Step Change Model; ADKAR Model	Leadership support is critical for ensuring commitment to the adoption process and aligning strategic goals across the organization. Leaders play a key role in driving the vision and ensuring employee buy-in.
B.4.7	The framework should clearly communicate the vision to align stakeholders.	Kotter's 8-Step Change Model; Lewin's Change Management Model	Clear communication of the IoT adoption vision ensures that all stakeholders understand the objectives, benefits, and processes involved, reducing uncertainty and increasing stakeholder alignment and support.
B.4.8	The framework could include early user training.	ADKAR Model; Lewin's Change Management Model	Early user training reduces resistance to change by ensuring that employees understand how to use IoT technologies and appreciate their practical benefits. Training also mitigates potential disruptions caused by lack of knowledge.
B.4.9	The framework must utilize pilots or demos.	Innovation Diffusion Theory (IDT); UTAUT; TAM	Pilots and demos allow organizations to test IoT technologies in controlled environments, showcasing their usefulness and minimizing the risk of failure in full-scale implementations.
B.4.10	The framework must deploy IoT in phases.	Lewin's Change Management Model; Kotter's 8-Step Change Model	A phased approach to IoT implementation allows organizations to manage changes more effectively, reduce operational disruptions, and adjust the strategy based on initial feedback and performance measurements.
B.4.11	The framework should incorporate user feedback mechanisms.	Kotter's 8-Step Change Model; ADKAR Model	User feedback mechanisms ensure continuous improvement in IoT adoption by capturing real-time data on how the technologies are being used and how the implementation process can be optimized.

B.4.12	The framework could leverage existing resources to reduce disruption.	Resource-Based View (RBV); Dynamic Capabilities Framework	Leveraging existing resources ensures minimal disruption to ongoing operations, making IoT adoption more cost-effective and reducing resistance by using familiar tools and infrastructure.
B.4.13	The framework must maintain a level of flexibility and adaptability.	Dynamic Capabilities Framework; Technology-Organization-Environment (TOE) Framework; Lewin's Change Management Model	Flexibility and adaptability in the framework allow organizations to adjust their strategies as new challenges arise or as technology evolves, ensuring long-term success in IoT adoption.
B.4.14	The framework must assess the implementation process's impact on operations.	Lewin's Change Management Model; Kotter's 8-Step Change Model; Technology-Organization-Environment (TOE) Framework	Regular assessments of how IoT adoption is affecting operational efficiency ensure that potential disruptions are identified early and corrective measures are taken to maintain productivity.
B.4.15	The framework must measure performance improvement.	Unified Theory of Acceptance and Use of Technology (UTAUT); Technology Acceptance Model (TAM); Dynamic Capabilities Framework	Measuring performance improvements allows organizations to evaluate whether IoT technologies are delivering the expected operational gains and to identify areas for further optimization.
B.4.16	The framework must evaluate technical availability.	Technology Readiness Index (TRI); Technology-Organization-Environment (TOE) Framework; Unified Theory of Acceptance and Use of Technology (UTAUT)	Technical availability assessments ensure that the necessary IoT technologies are reliable and accessible before full-scale adoption, reducing the risk of operational downtime and ensuring continuity.
B.4.17	The framework must assess the company's technical capabilities.	Technology Readiness Index (TRI); Technology-Organization-Environment (TOE) Framework; Resource-Based View (RBV)	A technical capabilities assessment ensures that the organization has the necessary infrastructure and expertise to support IoT adoption, identifying gaps that need to be addressed before implementation.
B.4.18	The framework must establish a thorough implementation plan before project execution.	Kotter's 8-Step Change Model; Lewin's Change Management Model; TOE Framework	Change management models and TOE Framework stress the need for structured implementation plans to align with organizational capabilities and reduce risk.
B.4.19	The framework must assess the company's organizational capabilities.	TOE Framework; UTAUT; ADKAR Model; Lewin's Change Management Model	Organizational capabilities are a key element in models assessing technology adoption, especially for understanding readiness and the role of human resources.

B.5: Integration of All Requirements

In this section, the requirements identified from two distinct sources—literature review and models analysis—are combined into a comprehensive list. The first set of requirements, derived from the literature review, emphasizes real-world challenges and best practices observed in IoT adoption across logistics sectors. These requirements primarily focus on addressing technical, organizational, and financial barriers to adoption, ensuring that key elements such as leadership, phased deployment, and stakeholder alignment are considered (see **Appendix B**, Section B.2).

The second set of requirements is drawn from established technology adoption models such as the Technology Readiness Index (TRI), Technology-Organization-Environment (TOE) Framework, Innovation Diffusion Theory (IDT), and others (see **Appendix B**, Section B.4). These models provide theoretical support, offering insights into the processes and strategies necessary for successful adoption, including readiness assessments, change management, and integration planning.

During the unification process, it became evident that certain requirements from both sets were closely aligned and complemented each other. For example, the need for readiness assessments (both technical and organizational) was highlighted in both the literature and models. Additionally, the models placed significant emphasis on measuring performance improvement and the gradual deployment of technologies, reinforcing similar findings from the literature.

An additional requirement was identified during this process due to the integration of insights from both sources. Requirement B.2.1 from the literature—"The framework must integrate technical, organizational, and financial aspects to tackle the multifaceted nature of IoT adoption"—highlighted the need for financial capability assessments alongside technical and organizational assessments. Therefore, a new requirement was added to assess financial capability, in line with requirements B.4.17 and B.4.19 ensuring a more holistic evaluation of readiness for IoT adoption. This ensures that organizations have the necessary resources not only to implement IoT solutions but also to sustain them long-term.

The resulting comprehensive set of requirements shown in **Table B.5** forms a robust framework that addresses both practical challenges and theoretical considerations, ensuring that IoT adoption in logistics is well-planned, systematically managed, and aligned with organizational capabilities.

Table B. 5: Integration of All Requirements

Req No.	Requirement Description	Supporting Models + Papers	Key Insights from Literature + Models
[1]	The framework must specify a stage-gate process needed to navigate the framework. This requirement ensures that users can systematically progress through the framework, enabling clear decision-making checkpoints.	Cooper (1990); Kotter's 8-Step Change Model	Stage-gate process improves project management, minimizes risks, and enhances decision-making checkpoints. Cooper's process emphasizes decision points and resource evaluation at each stage.
[2]	The framework must build on the work of other authors and established frameworks. This requirement aims to integrate existing knowledge and best practices into the framework, enhancing its academic and practical value.	Technology-Organization-Environment (TOE); ADKAR Model; Lee et al. (2015)	Using established frameworks and models ensures the framework is built on validated approaches and established best practices in IoT adoption.
[3]	The framework must integrate technical, organizational, and financial aspects to tackle the multifaceted nature of IoT adoption. This requirement ensures the various dimensions relevant for IoT implementation are addressed.	Technology-Organization-Environment (TOE); Dynamic Capabilities Framework; Lee et al. (2015); Ben-Daya et al. (2017)	IoT adoption is multifaceted, requiring integration across technical, organizational, and financial aspects for successful deployment. All elements must align to ensure holistic implementation.
[4]	The framework must assess technical, organizational, and financial readiness at early stages. This requirement ensures that potential barriers are identified in a timely manner, allowing for targeted mitigation strategies.	Technology Readiness Index (TRI); TOE; ADKAR Model; Ben-Daya et al. (2017)	Assessing readiness early enables the identification of key barriers (technical, organizational, financial), allowing mitigation strategies to be planned in advance.
[5]	The framework could build awareness around IoT benefits by sharing success stories. This requirement aims to enhance adoption by demonstrating the value and practical advantages of IoT technologies.	Innovation Diffusion Theory (IDT); Lee et al. (2015); Tang (2020)	Success stories help to create awareness and drive adoption by demonstrating practical benefits. Positive examples encourage organizations to take action.
[6]	The framework must establish a thorough implementation plan before project execution. This requirement ensures that the adoption process is well-structured, minimizes risks, and aligns with the organization's capabilities and resources.	Cooper (1990); Kotter's 8-Step Change Model; Lee et al. (2015)	A detailed implementation plan reduces risks and ensures alignment between organizational capacity and IoT demands. Structured execution enables better resource management.
[7]	The framework should foster leadership support. This requirement ensures that key decision-makers are committed to driving the IoT adoption process.	Kotter's 8-Step Change Model; Lewin's Change Management Model; Ben-Daya et al. (2017)	Leadership commitment is crucial to driving the process and ensuring that strategic decisions are backed by top management. Leadership provides direction and motivation for change.
[8]	The framework should clearly communicate the vision to align stakeholders. This requirement aims to ensure that all parties understand the objectives and support the IoT initiative.	Kotter's 8-Step Change Model; Lewin's Change Management Model; ADKAR Model	Clear communication helps align stakeholders to the project's goals and secures their support. Vision alignment ensures everyone understands the initiative's objectives and expected outcomes.
[9]	The framework could include early user training. This requirement prepares employees to use IoT technologies effectively, reducing resistance to change.	UTAUT; ADKAR Model; Lee et al. (2015); Ben-Daya et al. (2017)	Early user training eases the transition to IoT by reducing anxiety and resistance among employees, while boosting operational readiness and usability of new technologies.
[10]	The framework must utilize pilots or demos. This requirement aims to demonstrate IoT technologies' practical benefits, reducing uncertainty and fostering acceptance.	Kotter's 8-Step Change Model; ADKAR Model	Pilots help organizations reduce uncertainty and allow stakeholders to see practical benefits in action before full-scale deployment.
[11]	The framework must deploy IoT in phases. This requirement ensures a gradual and manageable implementation process, allowing for adjustments as needed.	Kotter's 8-Step Change Model; Lewin's Change Management Model; ADKAR Model; Cooper (1990)	A phased deployment allows organizations to make incremental improvements and respond to challenges that arise during implementation, minimizing disruption.
[12]	The framework should incorporate user feedback mechanisms. This requirement aims to facilitate continuous improvement based on actual user experiences.	UTAUT; ADKAR Model; Ben-Daya et al. (2017)	Incorporating user feedback allows for iterative improvements, ensuring that the IoT system meets the actual needs and requirements of its users.

[13]	The framework could leverage existing resources to reduce disruption. This requirement minimizes the impact on current operations and optimizes resource use.	Dynamic Capabilities Framework; Resource-Based View (RBV); Lee et al. (2015)	Leveraging existing resources minimizes disruptions and helps organizations optimize their current capabilities for IoT adoption, reducing implementation costs.
[14]	The framework must maintain a level of flexibility and adaptability. This requirement ensures that the framework can adjust to various contexts and organizational needs.	Dynamic Capabilities Framework; Resource-Based View (RBV); Lewin's Change Management Model; Ben-Daya et al. (2017)	Flexibility and adaptability in the framework allow organizations to respond to changes in internal and external environments, enhancing resilience in IoT adoption.
[15]	The framework must assess the implementation process's impact on operations. This requirement helps determine if IoT adoption is causing operational disruptions.	UTAUT; ADKAR Model	Operational impact assessments ensure that IoT deployment does not disrupt business continuity and allows for adjustment of processes as needed.
[16]	The framework must measure performance improvement. This requirement ensures that IoT adoption leads to measurable gains in operational efficiency.	Technology Acceptance Model (TAM); UTAUT; ADKAR Model	Performance measurement tools help track whether IoT adoption results in tangible improvements, justifying the investment and supporting continuous optimization.
[17]	The framework must evaluate technical availability. This requirement assesses the reliability and uptime of IoT technologies to ensure operational continuity.	Technology Readiness Index (TRI); Lee et al. (2015); Ben-Daya et al. (2017)	Evaluating technical availability ensures that IoT systems remain operational and that potential disruptions in service are minimized.
[18]	The framework must assess the company's technical capabilities. This requirement ensures the organization has the necessary technological infrastructure and expertise to support IoT adoption.	Technology Readiness Index (TRI); Technology-Organization-Environment (TOE); Ben-Daya et al. (2017)	Assessing technical capability ensures that companies are equipped with the necessary technological foundation for IoT deployment.
[19]	The framework must assess the company's organizational capabilities. This requirement evaluates the readiness of human resources and management to support IoT adoption.	Technology-Organization-Environment (TOE); ADKAR Model	Organizational capability assessments ensure that the workforce and management are prepared for the changes associated with IoT adoption.
[20]	The framework must assess company financial capability. This requirement ensures the organization has the financial resources to support the IoT project through its entire lifecycle.	Technology-Organization-Environment (TOE); Resource-Based View (RBV); Ben-Daya et al. (2017)	Financial capability assessments ensure that the organization can sustain IoT investment through its lifecycle, covering implementation and ongoing costs.

C

QUALITATIVE INTERVIEW ANALYSIS

Table C. 1: List of Interviewees

Interview #	Role	Background/Expertise
Interview 1	Innovations Manager	Expert in innovations for logistics (including IoT)
Interview 2	Engineering Manager	Expert in operations technologies; background in innovations (including IoT); background in IT
Interview 3	Project Engineer	Expert in operations/sort engineering; background in innovations (including IoT)
Interview 4	Industrial Engineer	Background in innovations adoption and properties design; backgound with IoT

Table C. 2: Analysis of Interview 1

Q#	Keywords/Codes	Meaning Units	Condensed Meaning Units	Category
Q1	No questions, happy with the recap	The respondent expressed no questions or need for clarifications and was satisfied with the introduction of the framework.	No clarifications needed; the respondent is satisfied with the framework introduction.	ITAF Evaluation
Q2	Applicability, structured framework, practical, end-to-end	The respondent finds the framework highly applicable to real-world environments, especially in logistics. They appreciate the end-to-end process it covers and see practical value in applying it to their own projects.	The framework is highly applicable to real-world environments, especially in logistics.	ITAF Evaluation
Q3	Similar but different, project specific, continuous improvement, structured evaluations	While FedEx's process is similar, it often deviates based on project specifics. They advocate for more consistency in structure and improvement, aligning it more closely with the framework.	FedEx's process is similar but lacks consistency; more alignment with the framework is needed.	ITAF Benefits
Q4	Project complexity, stage lengths, structured timeline	Depending on project complexity, large projects take 1–1.5 years. The respondent provided specific timelines for each stage, with Stage 0 taking 2–4 weeks, and subsequent stages having their own detailed timelines.	Large projects take 1–1.5 years, with Stage 0 taking 2–4 weeks and detailed timelines for other stages.	Timelines
Q5	Complexity, size of solution, back-and-forth between stages	FedEx projects often take 1.5 to 4 years, with complexity and project size playing a significant role. Delays frequently result from back-and-forth adjustments between stages, especially due to inadequate early-stage planning.	FedEx projects take 1.5 to 4 years; delays often result from inadequate early-stage planning.	Timelines
Q6	RACI model, cross-functional teams, innovations team ownership	Ownership is managed using the RACI model, with the innovations team taking primary responsibility for the project until handover to other teams after launch. Multiple departments are involved throughout the process.	The RACI model is used for ownership, with the innovations team leading until handover post-launch.	Ownership
Q7	Management oversight, gate approvals, business case prioritization	Leadership is highly involved at key gates (Gate 1, Gate 2) for project prioritization and budget approvals. Their involvement becomes more informal at later gates, where technical decision-making is delegated to the innovations team.	Leadership is involved in early gates (prioritization, budget), with technical decisions delegated later.	Ownership
Q8	Cross-functional delays, department priorities, misalignment	Multiple teams contribute to delays due to differing departmental priorities. Clear communication and prioritization are necessary to minimize these delays, with each department pushing its own agenda for the project.	Multiple teams cause delays due to different priorities; clear communication and prioritization are needed.	Ownership
Q9	Feedback loop, lessons learned, continuous improvement	Post-launch reviews are critical for gathering feedback. These lessons inform future projects, creating a loop of continuous improvement. This is particularly important after the solution is handed over to other teams.	Post-launch reviews are crucial for continuous improvement and are needed after handover to other teams.	Timelines
Q10	Labor shortage, skilled workforce, technical challenges, financial fluctuations	Organizational challenges stem from labor shortages, technical challenges involve adapting to rapidly evolving technology, and financial constraints are dictated by external macroeconomic factors. Priorities shift based on market trends.	Organizational challenges include labor shortages, technical adaptation, and financial constraints influenced by market trends.	3PL Challenges
Q11	Financial viability, ROI, profitability, technology investment	Financial factors play a central role in FedEx's decision-making process. Every technology must justify its value through ROI, and financial constraints are a major consideration for whether projects proceed.	Financial factors and ROI are central to decision-making, and financial constraints impact project continuation.	3PL Challenges
Q12	Technology-specific KPIs, general framework, customization	KPIs are hard to generalize due to the varied nature of technologies. The respondent suggests that the framework should allow for customizable KPIs specific to each technology to ensure accurate measurement.	KPIs should be customizable for each technology to ensure accurate measurement.	ITAF Evaluation
Q13	Technical, organizational, financial, performance improvement, completeness	The evaluation metrics in the framework are seen as comprehensive, covering the necessary areas for project evaluation (technical, organizational, financial). The respondent finds the metrics complete and doesn't recommend changes.	Evaluation metrics are comprehensive and do not need changes.	ITAF Evaluation
Q14	Complete framework, feedback loop, improvement suggestions	The respondent finds the framework complete but emphasizes the value of incorporating feedback from current project into future projects to create a continuous improvement loop, which is crucial for refining the process.	Incorporating feedback from current project is essential for continuous improvement in future projects.	ITAF Improvement
Q15	Long-term focus, prioritizing technology, RFID, data-driven decisions	FedEx has focused on IoT for over seven years, prioritizing RFID for data collection and decision-making. They have increasingly recognized the value of technology adoption in their operations.	FedEx has focused on IoT for over seven years, prioritizing RFID for data collection and decision-making.	3PL Challenges

Q16	Few completed projects, more in the US, Europe slower	Only one IoT project was fully completed in Europe, with more projects completed in the US. Europe has only recently begun prioritizing innovation, largely in response to labor shortages.	Only one IoT project was fully completed in Europe, while the US has completed more.	3PL Challenges
Q17	Business needs vs. technology readiness, long timelines, evolving environments, component availability, financial constraints	Many projects were not completed due to misalignment between business needs and the readiness of technology, evolving environments during long timelines, and external constraints like component shortages and financial challenges.	Projects were halted due to misalignment between business needs and technology readiness, evolving environments, and external constraints.	3PL Challenges
Q18	First European IoT project, use of RFID	RFID on Blue Cages was the first IoT project in Europe, but similar innovations had already been adopted in the US.	RFID on Blue Cages was the first IoT project in Europe, though similar innovations existed in the US.	3PL Challenges
Q19	Inventory management, loss of assets, tracking challenges, deployment issues, lack of user engagement	The RFID on Blue Cages project was aimed at tracking assets but faced issues due to the lack of infrastructure (RFID readers) and insufficient user engagement, leading to its eventual failure.	The RFID on Blue Cages project failed due to infrastructure issues and lack of user engagement.	3PL Challenges
Q20	Implementation issues, lack of planning, failure to engage end users	The RFID project failed primarily due to poor planning and lack of contingency for scenarios where users didn't follow procedures. There was also insufficient effort to engage end users, leading to the project's abandonment.	The RFID project failed due to poor planning, lack of user engagement, and no contingency for non-compliance.	3PL Challenges
Q21	Success, active RFID, temperature monitoring, customer satisfaction	The SenseAware project was a success due to robust testing, meeting customer needs, and strong engagement. It involved monitoring temperature-sensitive items and provided high customer satisfaction, making it a success in the US.	SenseAware succeeded due to robust testing, meeting customer needs, and strong customer satisfaction.	ITAF Evaluation
Q22	Experience, resources, thorough testing, prioritization	The success of SenseAware is attributed to larger, more experienced teams in the US, as well as thorough testing and better resource prioritization. FedEx US had more experience in IoT than Europe, leading to better project outcomes.	SenseAware succeeded due to experienced US teams, better testing, and resource prioritization.	Ownership
Q23	US more advanced, larger teams, shared lessons	The US is more advanced in IoT adoption due to larger, more experienced teams. However, Europe learns from US projects through strong communication, leveraging lessons learned to improve their own IoT implementations.	The US is ahead in IoT adoption due to larger teams; Europe learns from US experiences to improve.	Ownership
Q24	Framework applicability, alignment with US approach	The respondent believes the framework aligns with the US approach and finds it more structured than the US's existing framework, making it a valuable tool for both regions.	The framework aligns with the US approach and is more structured, making it valuable for both regions.	ITAF Evaluation
Q25	Feasibility, infrastructure readiness	The respondent is confident in the feasibility of implementing SenseAware in Europe, assuming the necessary infrastructure is in place. They see strong potential for this project in European locations.	SenseAware is feasible in Europe if the necessary infrastructure is in place.	3PL Challenges
Q26	Resource allocation, end-user engagement, infrastructure readiness	Two key challenges for introducing SenseAware in Europe are resource allocation and end-user engagement. However, there is growing interest in new technologies among end users, which could facilitate the project's success.	Resource allocation and end-user engagement are key challenges, but growing interest in new tech may aid success.	3PL Challenges
Q27	Improvement, applicability beyond IoT, structure	The respondent sees value in the framework for improving IoT adoption at FedEx, noting its potential to be applied to non-IoT projects as well. They highlight the framework's structure as its key strength.	The framework improves IoT adoption and is applicable beyond IoT, with its structure being a key strength.	ITAF Benefits
Q28	Prioritization, resource allocation, collaboration with US	Recommendations for improving IoT success at FedEx include better resource allocation, maintaining synergies with US teams, and securing adequate budgets to support the initiatives.	Recommendations include better resource allocation, stronger US collaboration, and securing budgets for IoT success.	—
Q29	Broad applicability, project structuring, smaller companies	The respondent believes the framework has broad applicability across industries and could be particularly valuable for smaller companies, helping them establish structured processes for managing complex projects.	The framework is broadly applicable across industries, especially for helping smaller companies manage complex projects.	ITAF Evaluation

Table C. 3: Analysis of Interview 2

Q#	Keywords/Codes	Meaning Units	Condensed Meaning Units	Category
Q1	Introduction, ITAF, clarifications	No clarifications needed, everything is clear.	No clarifications required; everything is clear.	ITAF Evaluation
Q2	Impressions, adjustments	The framework is adaptable and can be customized to company needs, particularly suited to business as usual and production environments. No adjustments are necessary.	The framework is adaptable, especially for production environments, and no changes are necessary.	ITAF Evaluation
Q3	Comparison, FedEx, IoT adoption	FedEx has an innovation framework without a dedicated IoT process. The innovation stages in the interviewee's model are similar to ITAF but have some shortcuts, especially in challenge identification.	FedEx's innovation framework is similar to IoT processes but lacks a dedicated IoT adoption approach.	ITAF Evaluation
Q4	Timeframes, average time per stage	Stage 0 is continuous; Stage 1: 2 weeks; Stage 2: 2 weeks to 1 month; Stage 3: no more than 3 months. Timelines depend on technology and complexity.	Stages are quick, especially Stage 1-2, but timelines depend on technology and complexity.	Timelines
Q5	Timeframes at FedEx, process comparison	Stage 1-3 in FedEx can be as short as 4 months. Delays occur in software development. Lessons learned speed up large-scale implementations (Stage 4).	Stages 1-3 at FedEx can be completed within 4 months, with software delays affecting larger rollouts.	Timelines
Q6	Decision ownership, stage ownership	Stage 0 involves R&D/innovation; Stage 1 and 2 involve innovation plus higher management for financials; Stage 4 involves the team using the technology and implementers.	Each stage involves specific teams, including innovation, management, and implementation teams.	Ownership
Q7	Management input, gate decisions	Key management input at Gate 2 (financials, process optimization), and Gate 4 (measurable KPIs). Too many stakeholders hinder decision-making at these gates.	Decision gates for financials and KPIs are key; too many stakeholders can slow decision-making.	Ownership
Q8	Teams, involvement, delays	The large number of stakeholders in Stage 0 helps identify ideas, but later stages (2-4) require fewer people. Ownership and end-user involvement are critical for progress.	Involving many stakeholders early is key, but fewer are needed in later stages for efficiency.	Ownership
Q9	Post-launch review, ownership	Post-launch review should be at the end of implementation. The review involves the innovation team and the team using the technology to assess long-term benefits.	Post-launch review is essential for long-term evaluation, involving both innovation and user teams.	Timelines
Q10	Challenges, FedEx, technological, organizational, financial	FedEx faces challenges in Europe with legacy systems, organizational changes, and financial limitations. Regional differences lead to tailored solutions across regions.	FedEx faces regional, organizational, and financial barriers in adopting new technologies.	3PL Challenges
Q11	Financial weight, 3PL, IoT adoption	Financial considerations are crucial. FedEx often collaborates with vendors to co-develop technologies, which reduces pilot costs. New technologies are more expensive in early stages.	Financial considerations are critical, and vendor collaborations help mitigate pilot costs.	3PL Challenges
Q12	KPIs, technology-specific KPIs	KPIs should be defined in Stage 0. They are case-specific but return on investment (ROI) is the most important metric in any IoT project.	KPIs must be defined early, and ROI is the key metric.	ITAF Improvement
Q13	Project review, evaluation metrics	The review metrics in the framework are comprehensive. Suggested improvement: combine projects radar charts for faster decision-making.	Review metrics are complete but could combine projects radar charts for faster decisions.	ITAF Improvement
Q14	Additional thoughts	No additional comments.	No additional comments.	ITAF Evaluation
Q15	IoT adoption, past projects	SenseAware was the most significant IoT project, implemented in the US first, and Europe followed. Previous RFID on Blue Cages was another key project, though older.	SenseAware and RFID on Blue Cages were the most significant IoT projects.	3PL Challenges
Q16	Uncompleted IoT projects	FedEx had only a few IoT projects that didn't proceed to full implementation, mostly due to aviation security regulations and health and safety constraints.	Few IoT projects were fully implemented, mainly due to regulatory and safety concerns.	3PL Challenges
Q17	Stuck stages, uncompleted projects	Most projects stalled at Gate 4 due to financial reasons. As technologies mature, their costs drop, making early-stage adoption expensive.	Projects often stalled at Stage 4 due to financial constraints.	3PL Challenges
Q18	First IoT project, Blue Cages	RFID on Blue Cages was FedEx's first IoT-related project in Europe. It was successful but became obsolete due to advancements in loading technology.	RFID on Blue Cages was successful but became outdated due to technological advancements.	3PL Challenges

Q19	Blue Cages project summary	The project used RFID tags on Blue Cages to track transport containers. It optimized the sorting and management of containers, but its need diminished over time.	RFID on Blue Cages optimized container management but became unnecessary as technology advanced.	3PL Challenges
Q20	What went wrong, lessons learned	Nothing went wrong with RFID on Blue Cages, but the need for blue cages has diminished due to other technologies improving loading and transportation processes.	RFID on Blue Cages was not problematic but became redundant due to technological improvements.	3PL Challenges
Q21	SenseAware, project summary	SenseAware was developed to exceed customer expectations, particularly for time-critical shipments like medical items. The project succeeded, though Stage 4 (large-scale implementation) was slow.	SenseAware focused on critical shipments and customer needs but faced slow large-scale implementation.	3PL Challenges
Q22	Success vs. uncompleted projects	SenseAware succeeded because of clear ROI and improved customer experience, which justified large-scale implementation.	SenseAware succeeded due to strong ROI and customer experience improvements.	ITAF Benefits
Q23	US vs. Europe innovation approach	Initially, there was a lack of alignment, but now regions like Europe and the US coordinate their innovation efforts to avoid duplication.	US and European innovation efforts were initially siloed but are now better aligned.	Ownership
Q24	US framework applicability	The framework is globally applicable, and early stages (0-2) can be done at the global level, with stages 3-4 handled regionally to fast-track adoption.	The framework is globally applicable, with earlier stages centralized and later stages regionalized.	ITAF Evaluation
Q25	SenseAware in Europe, feasibility	SenseAware is being implemented in Europe, though on a smaller scale compared to the US.	SenseAware is in progress in Europe, though on a smaller scale compared to the US.	3PL Challenges
Q26	Key considerations, blockers	Financial limitations and differing mentalities across countries (resistance to change) are major barriers to SenseAware's full-scale adoption in Europe.	Financial constraints and regional resistance hinder full-scale SenseAware adoption in Europe.	3PL Challenges
Q27	IoT framework benefits, FedEx	The framework provides clarity and structure, benefiting FedEx's IoT adoption process. Standardization helps streamline decision-making and communication.	The framework clarifies IoT adoption processes and improves standardization.	ITAF Benefits
Q28	Recommendations for FedEx IoT success	FedEx should stabilize its foundations before fully focusing on innovation. Regional collaboration and solid infrastructures are necessary for IoT success.	FedEx needs a stable foundation and better regional collaboration for IoT success.	ITAF Benefits
Q29	Broader use of ITAF	The framework is flexible enough to be applied to various industries and processes, formalizing innovation and providing structure across different contexts.	The framework is adaptable across industries, formalizing processes for different applications.	ITAF Evaluation

Table C. 4: Analysis of Interview 3

Q#	Keywords/Codes	Meaning Units	Condensed Meaning Units	Category
Q1	Clarifications, logical, questions	No questions; everything seems logical so far.	No clarifications needed; framework is logical.	ITAF Evaluation
Q2	Feedback loops, financial impact	The framework aligns with FedEx's feedback loops. Financial impact (monetization) is the main focus now and considered as the primary goal rather than a mere KPI.	The framework aligns with FedEx's processes; financial impact is the main focus now.	ITAF Evaluation
Q3	Comparison, IoT adoption process	FedEx's IoT adoption process is less structured and has flexible stage gates, often influenced by external factors like cyber-attacks or COVID-19.	FedEx's IoT process is less structured, with flexible stage gates and external influences like cyber-attacks.	ITAF Evaluation
Q4	Timeframes, ideal, project delays	Stages should ideally take one quarter each, maximum two. Complex projects and changing factors can result in setbacks that push teams to restart stages.	Stages should take 1-2 quarters each, but complex projects often face setbacks.	Timelines
Q5	FedEx timelines, long projects	FedEx projects often take too long. Piloting is quick, but large-scale implementations can drag on for years due to approvals, technical issues, or external factors.	FedEx projects take too long due to long approval processes and technical issues.	Timelines
Q6	Ownership, decision process	Initially driven by finance, decision-making now involves operations and P&E, but central P&E sometimes creates a mismatch with local operations' expectations.	Decision-making has shifted from finance to operations but still faces alignment issues between central and local teams.	Ownership
Q7	Project team, management input	Management should approve decisions but not dictate timelines. The project team's technical advice must lead, otherwise pressure from management leads to rushed and suboptimal solutions.	Management should approve but not dictate timelines; technical advice should lead to avoid rushed solutions.	Ownership
Q8	Decision-making, delays, autonomy	Delays happen when many people/teams are involved. Decentralized decision-making often clashes with centralized goals, slowing the implementation of technology.	Too many teams slow implementation; decentralized decisions clash with centralized goals.	Ownership
Q9	Post-launch review, feedback loop	Post-launch reviews should be continuous, not only at the end (80%). Feedback loops at multiple points can help fine-tune and optimize the large-scale implementation.	Continuous reviews with feedback loops at multiple stages are needed. Post-launch at 80% of rollout.	ITAF Improvement
Q10	Challenges, resistance to change	The main challenges are behavioral resistance to change and external factors like company takeovers, cyberattacks, and organizational shifts, impacting adoption.	Main challenges include resistance to change and external factors like takeovers and cyberattacks.	3PL Challenges
Q11	Financial weight, adoption success	Financial considerations are important, but it's hard to predict the benefits upfront. You may generate idle time, but if unused, the financial gain is theoretical.	Financial impact is important but hard to predict upfront; some benefits may remain theoretical.	3PL Challenges
Q12	KPIs, technology-specific	KPIs are hard to define generically because they depend on the technology. General KPIs may need to be adapted based on the specific project or technology being used.	KPIs must be technology-specific and adapted for each project.	ITAF Evaluation
Q13	Review metrics, adaptability	The review metrics can be adapted based on the project type, but external factors like cyberattacks and outdated tech during implementation impact success rates.	Review metrics are adaptable, but external factors impact success rates.	ITAF Improvement
Q14	Additional comments	No additional comments.	No further comments provided.	ITAF Evaluation
Q15	IoT projects, small-scale	FedEx has run many small-scale IoT projects, typically focused on specific solutions that showed quick and tangible benefits.	FedEx has run many small-scale IoT projects with quick and visible benefits.	3PL Challenges
Q16	Completed projects, production use	Some projects ran for years in production but were phased out. RFID tags in Memphis are still in use, though the Blue Cages in Europe are no longer active.	Some projects ran for years but were phased out; RFID is still in use in Memphis, but Blue Cages are inactive in Europe.	3PL Challenges
Q17	Stuck projects, pilot phase	Many projects get stuck after the pilot phase, before large-scale implementation. The evaluation phase may reveal that the technology is not fit for purpose, halting progress.	Many projects get stuck after pilots due to unsuitable technology or other reasons.	3PL Challenges
Q18	Blue Cages, early IoT projects	The Blue Cages project was one of the first large-scale IoT projects at FedEx (previously TNT). Small-scale security initiatives also existed (e.g., GPS trackers).	Blue Cages was one of FedEx's first large-scale IoT projects, with small-scale security projects like GPS also in use.	3PL Challenges
Q19	Blue Cages, project summary	Blue Cages helped coordinate the distribution of cages between locations, ensuring supply met demand across regions, but its relevance diminished over time.	Blue Cages optimized cage distribution, but relevance decreased over time.	3PL Challenges

Q20	Lessons, project abandonment	The project succeeded initially but became irrelevant once cage management became predictable. The FedEx-TNT takeover also led to discontinuation of Blue Cages.	Blue Cages succeeded but became irrelevant as operations became predictable and the FedEx-TNT merger phased them out.	3PL Challenges
Q21	SenseAware, Europe implementation	SenseAware is being pushed from the US, but challenges exist in Europe around logistics (PUD drivers returning devices) and cultural differences in operations.	SenseAware is being introduced in Europe, but faces logistical and cultural challenges.	3PL Challenges
Q22	—	—	—	—
Q23	Innovation adoption, FedEx US vs EU	US and Europe share similar innovation adoption processes, with an emphasis on avoiding duplication. SenseAware should succeed globally if proven in the US.	US and Europe have aligned processes, and SenseAware should succeed globally if successful in the US.	ITAF Evaluation
Q24	—	—	—	—
Q25	SenseAware, feasibility in Europe	SenseAware has potential in Europe for high-priority goods but may not be cost-effective for lower-priority items. The operational model may need adjustment.	SenseAware has potential in Europe for high-priority goods but may not be cost-effective for others.	3PL Challenges
Q26	Implementation challenges, networks	European networks may present challenges due to legacy TNT infrastructure, which may not be fully compatible with new technologies like SenseAware.	Legacy TNT infrastructure in Europe may present compatibility challenges with new tech like SenseAware.	3PL Challenges
Q27	Framework benefits, IoT adoption	The framework would benefit FedEx by encouraging focus on projects with higher success potential, avoiding wasted time on less viable initiatives.	The framework helps FedEx focus on high-potential projects and avoid wasting time on low-viability initiatives.	ITAF Benefits
Q28	Collaboration, external partners	FedEx should collaborate more with external partners and academia, instead of trying to develop proprietary solutions that are often less advanced than market offerings.	FedEx should collaborate with external partners instead of focusing on less advanced internal solutions.	—
Q29	Broader application of the framework	The framework is broadly applicable beyond IoT and to other companies and technologies. Planning the scale-up phase early is essential for success.	The framework is adaptable beyond IoT and applicable to various technologies, with early scale-up planning key for success.	ITAF Evaluation

Table C. 5: Analysis of Interview 4

Q#	Keywords/Codes	Meaning Units	Condensed Meaning Units	Category
Q1	Clarifications, clear	No clarifications needed; everything is clear.	No clarifications needed, everything is clear.	ITAF Evaluation
Q2	Accurate to reality, innovation	The framework aligns well with the real-world experience of implementing innovative projects, such as IoT, that FedEx has recently explored.	The framework aligns well with FedEx's innovation processes, including IoT projects.	ITAF Evaluation
Q3	Comparison, current process, vendors	The framework is comparable to FedEx's current IoT project process and includes vendor collaboration.	The framework is comparable to FedEx's IoT process and involves vendor collaboration.	ITAF Evaluation
Q4	Timelines, decision ownership	Timelines can vary depending on the technology and vendor. Ideally, the total process should take one year, but timelines fluctuate based on complexity.	Timelines vary by technology and vendor, ideally taking one year but often fluctuating.	Timelines
Q5	FedEx timelines, delays	At FedEx, stages 0 and 1 are fast (one or two months each), but delays often occur during planning and piloting due to external factors like vendor delays.	Stages 0 and 1 are fast, but external factors cause delays during planning and piloting.	Timelines
Q6	Ownership, cross-functional teams	The project team owns stages 0-3, with cross-functional collaboration. For large-scale rollout (stage 4), the rollout team takes over.	The project team owns stages 0-3, and the rollout team takes over for stage 4.	Ownership
Q7	Decision power, management input	Management plays a key role in decision-making between stages 1-2 (planning) and stages 3-4 (pilot to rollout).	Management is key in decision-making between planning and rollout stages.	Ownership
Q8	Cross-functional teams, delays	Involving many teams creates delays, but their input is essential. Misalignments between teams can slow progress, but their involvement is key to success.	Involving multiple teams causes delays, but their input is essential for success.	Ownership
Q9	Post-launch review, collaboration	Post-launch reviews should be a collaboration between the project and rollout teams, ideally comparing rollout results with pilot results.	Post-launch reviews should involve both project and rollout teams, comparing results to the pilot.	Ownership
Q10	Challenges, financial, organizational	Financial constraints (limited budget) are a major barrier in Europe. Organizationally, innovation acceptance is challenging, especially training and adoption.	Financial constraints and resistance to innovation are major challenges in Europe.	3PL Challenges
Q11	Financial weight, ROI, long-term	The focus on financial ROI has increased over the years. IoT projects, especially costly ones like robotics, often require a longer-term ROI outlook.	ROI focus has increased, and IoT projects often require a long-term financial outlook.	ITAF Improvement
Q12	KPIs, project-specific, generalizable	KPIs are highly specific to the technology, although some general KPIs (like piece-per-hour) can apply. Project-specific KPIs are necessary to evaluate success.	KPIs are technology-specific, though general KPIs can apply; project-specific KPIs are critical.	ITAF Evaluation
Q13	Project metrics, decision-making	The framework covers the metrics well. Decision-making KPIs should be included under performance improvement, as decisions impact project outcomes.	The framework covers metrics well, but decision-making KPIs should be included under performance.	ITAF Improvement
Q14	No additional comments	No additional comments on this section of the framework.	No further comments on this section.	ITAF Evaluation
Q15	IoT adoption, Europe	There have been efforts, but few IoT projects in Europe have progressed beyond the pilot phase. FedEx aims to prioritize IoT projects in the future.	Few IoT projects in Europe have progressed past the pilot phase; IoT is becoming a priority.	3PL Challenges
Q16	Completed projects, Europe	No fully completed IoT projects in Europe within the past five years. A predictive maintenance pilot did not result in a full rollout.	No completed IoT projects in Europe in the last five years; pilots didn't reach full rollout.	3PL Challenges
Q17	Stuck projects, budget constraints	Projects often get stuck between stages 1 and 2 (assessment) due to high costs, or between pilot and rollout due to resource and data scaling issues.	Projects stall between assessment and rollout stages due to high costs and scaling issues.	3PL Challenges
Q18	Blue Cages, RFID, tracking	The Blue Cages RFID project aimed to track cages but was not fully implemented. It became obsolete after FedEx-TNT integration and changing operational needs.	Blue Cages RFID project wasn't fully implemented and became obsolete after FedEx-TNT integration.	3PL Challenges
Q19	Blue Cages, scope, tracking data	The Blue Cages project focused on tracking cages across the network but was ultimately not used widely due to operational changes.	Blue Cages tracked containers but was not widely used due to operational changes.	3PL Challenges
Q20	Lessons, data utilization, integration	Data from the RFID system was collected, but there was likely no follow-up or use of the data. The integration phase may have been lacking or uncoordinated.	RFID data was collected, but no follow-up or use occurred; integration was likely uncoordinated.	3PL Challenges

Q21	SenseAware, knowledge, success	Limited knowledge about SenseAware, but feedback suggests moderate success. SenseAware may have benefited from clearer objectives or better execution.	Limited knowledge on SenseAware, though feedback suggests moderate success.	—
Q22	—	—	—	—
Q23	FedEx US vs Europe, alignment	FedEx US and Europe have become more aligned in their innovation adoption approach over the past few years. Collaboration and standardization have improved.	US and Europe have aligned their innovation adoption processes, with improved collaboration and standardization.	ITAF Evaluation
Q24	Framework applicability, general use	The framework is general enough to be applied to other companies or regions, regardless of local policies or technological differences.	The framework is general and applicable to other companies, regions, and technologies.	ITAF Evaluation
Q25	—	—	—	—
Q26	—	—	—	—
Q27	Framework, benefit to FedEx	The framework would be beneficial to FedEx and other companies because it offers structure for the implementation of technology projects like IoT.	The framework offers structure and benefits FedEx and other companies in technology projects.	ITAF Benefits
Q28	Recommendations, analytics, training	Emphasize data analytics and visualization tools for IoT projects. Users need proper training to utilize the data effectively and improve decision-making.	Focus on data analytics and visualization tools; user training is key for decision-making.	—
Q29	Broader use of framework	The framework is applicable to other technologies and companies, not just IoT. Its steps align with the processes used in various types of innovation projects.	The framework applies to other technologies and companies, beyond IoT, and aligns with other innovation processes.	ITAF Evaluation

D

ITAF PROJECT EVALUATION EXAMPLE

Description: A sample of 10 FedEx IoT projects/initiatives were selected by the interview participants and evaluated retrospectively using the Stage-Gate process, as well as the Project Evaluation Metrics proposed by ITAF. ITAF is a framework meant to guide IoT projects during the process of adoption. However, due to the actual timelines of such projects (at FedEx, between 1.5 to 4 years, see **Appendix C**) and within the time limits of this MSc thesis research, applying the entire framework to an ongoing project was not feasible. As such, the most appropriate alternative for evaluating the applicability of the framework in practice was through a reflective assessment of past IoT adoption projects within the company. The four interview participants filled in their evaluations of the projects individually, after which the results were aggregated, as seen in the tables below. In this section, an example of potential insights drawn from the (retrospective) application of the framework is presented.

The purpose of this exercise is two-fold:

1. Evaluate the applicability of ITAF in the context of practical adoption projects − observe if the FedEx projects can be tracked through their adoption process using ITAF and if the framework can indicate areas of improvement for future initiatives.
2. Draw any potential improvements for the ITAF prototype – observe if lessons learned from these projects can indicate the need for improvements in the framework.

Note: For a more thorough evaluation of ITAF in practice, future applications of the framework over the course of an entire project are desired and present an opportunity for future research.

D.1: Example of ITAF Stage-Gate Process Retrospective Evaluation

This analysis is informed by **Table D.1** below.

Abandoned Projects: Half of the abandoned projects were stopped during Stage 1 (P1 and P6), and they both cite insufficiencies in technical capability as the reason. This is not seen as an issue in ITAF, as it indeed confirms the purpose of Stage 1: Capability Assessment. Stopping at this stage is safe and recommended, rather than continuing with a solution with a high chance of failure. More concerning is the other half of the 'abandoned' group (P2 and P8): projects failing at Gate 4/Stage 4 are an indicator of (1) incomplete/inappropriate planning or (2) overestimated capability assessment results that do not reflect reality. Lessons learned for the company: (LL1) apply a more thorough approach to assessing capabilities and/or formulating a plan for future projects. Improvement for framework: (IF1) include a capability re-assessment after pilot testing, as well as a review of the large-scale implementation plan.

Returned/Revised Projects: Two-thirds of the returned projects were stopped at Gate 1 (P3, P4). Two insights can be drawn from this: (3) The company is showing active interest in IoT technology adoption, which is a good indicator of a good culture of innovation. (4) The company is not afraid of failing early, which means they are thorough in searching for the best IoT alternative for their needs. An interesting outlier, however, is P5, which returned from Gate 4 (post-pilot, prior to implementation) all the way back to Stage 0. This is marked in the comments as an organizational capability issue: the project ownership at or after Gate 4 was not well-defined. Lessons learned for the company: (LL2) set clear roles and responsibilities, (LL3) allocate the appropriate resources, or else (LL4) don't invest in the project if the organizational capabilities don't allow it. This stresses the importance of early (organizational) capability assessment and appropriate change management. Improvement for the framework: (IF2) set a clear guideline for ownership at each stage.

Ongoing Projects: Two projects (P9 and P10) are still ongoing. P10 is still early in the adoption process during the assessment of the company's capabilities. Therefore, no insights can be drawn yet from this project. P9, however, has already reached Gate 4, meaning it's currently at post-pilot, prior to the implementation phase. At first glance, this would be a good sign, seeing as the project has made significant progress so far. However, as observed from the abandoned and returned/revised projects, this particular gate poses the highest risk throughout the entire adoption process (at least for FedEx). As such, the higher probability is that of not passing to Stage 4. In order to increase its chances of success, the company should have implemented the feedback from previous projects, such as the ones discussed here.

Successful Implementation: P7 stands out as the only completed project in this list, having finalized both the implementation and the post-launch review (PLR). This shows that it successfully navigated the ITAF process. Lessons learned for the company: (LL5) successful projects like this one represent the ideal benchmark for establishing best practices for any future initiatives. Improvement for the framework: (IF3) indicate clearly in the ITAF diagram that insights from past projects should become lessons learned for future ones.

All observed insights from this analysis are captured in **Table D.2**.

Table D. 1: Aggregate results of project evaluation sheets: ITAF Stage-Gate Process

P#	S0	G1	S1	G2	S2	G3	S3	G4	S4	PLR	Comments
P1	✓	✓	Abandon								Quick test with equipment showed significant technical issues
P2	✓	✓	✓	✓	✓	✓	✓	✓	Abandon		Worked and helped but not in use anymore
P3	✓	Return									Integration with IT infra, strict data security requirements
P4	✓	Return									Ideas were investigated but technical capability was insufficient
P5	✓	✓	✓	✓	✓	✓	✓	Return to S0			Organizational issues: Lack of clear ownership
P6	✓	✓	Abandon								Implemented outside EU; blocked due to privacy regulation (technical issue)
P7	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Deployed in US (initial stages in EU)
P8	✓	✓	✓	✓	✓	✓	✓	Abandon			Stopped at the end of the pilot period
P9	✓	✓	✓	✓	✓	✓	✓	Ongoing			Ongoing
P10	✓	✓	✓	Ongoing							Currently at early stage

Acronyms used: P – IoT project, S – stage (S0 – stage zero), G – gate (G1 – gate one), PLR – Post-launch review
Legend: Green – passed, Red – Return/Abandon, Orange – Ongoing, Grey – N/A

Table D. 2: Insights from the analysis of the ITAF Stage-Gate Process

Lessons Learned for the company	Improvements for framework
LL1: Apply a more thorough approach to assessing capabilities and formulating a plan.	**IF1**: Re-assess capabilities after pilot testing and review the large-scale implementation plan.
LL2: Set clear roles and responsibilities from the start.	**IF2**: Establish clear guidelines for ownership at each stage.
LL3: Allocate appropriate resources for each stage.	**IF3**: Clearly indicate in the ITAF diagram that insights from past projects should inform future ones.
LL4: Do not invest if organizational capabilities are insufficient.	
LL5: Use successful projects as benchmarks for future best practices.	

D.3: ITAF Stage-Gate Process Evaluation

This analysis is informed by **Table D.3** below.

1. Technical Capability: Most projects show strong technical capability, with five out of nine evaluated projects scoring 4.00 or above (P2, P5, P6, P7, and P9). This suggests that for the majority of these IoT solutions, the technical requirements were not a significant barrier to adoption in the later stages. Indeed, it was observed in D.1 that all projects indicating technical issues (in the comments) were abandoned or revised early in the adoption process. This metric supports the stage-gate process evaluation findings.

2. Organizational Capability: The organizational capability is consistently low across most projects, with seven out of nine scoring 2.00 or below. This highlights a recurring issue in how the company handles change management, employee training, and overall readiness to adopt new IoT technologies. Only P7 and P9 show relatively strong organizational capability, suggesting better management or user adoption in these instances. Due to P7's adoption success in D.1 and P9's ongoing progress supported by strong organizational capabilities, it can be implied that some lessons learned from P7 were already applied. The trend observed here is that change management is improving in the latest projects.

3. Financial Capability: The financial capability for most projects sits in the middle of the grading scale. This shows the company's reluctance to invest significant amounts into IoT technology. However, IoT technologies across the board entail high initial investments and long-term returns. This could explain why the company is so selective and risk-averse with its IoT initiatives (this further supports the findings in D.1). As such, another lesson learned is observed here: (LL6) Financial capabilities should be evaluated and planned more realistically, considering the high up-front costs of IoT. In terms of outliers, the low score for P3 is in line with its reason for revision at Stage 1 in D.1, indicating a good evaluation of financial capabilities. Similarly, P6 scored the highest on this metric but was abandoned early due to technical limitations.

4. Performance Improvement: All of the projects that scored high on performance improvement were either completed successfully (P7) or abandoned/revised for other reasons (P2, P4, P5, P6). There is no other observable trend regarding this metric from the sample of 10 projects. However, the average score of P9 for performance improvement, along with the low financial capability, further supports the low chances of success at its current step in the process, Gate 4 (this is in line with the insights from D.1).

5. Implementation Process Impact: The only relevant projects for this metric are P2, P5, P7, P8, and P9, as they are the only projects that progressed far enough in the adoption process to accurately predict this metric. P2 and P5 are both attributed high scores, indicating this metric did not play a role in their abandonment/revision (this is in line with insights from D.1). The lowest score attributed to P8 could indicate the reason why this project was abandoned after the pilot.

6. Technical Availability: This metric is generally high for most projects, with only P8 and P9 scoring below 4.00. Technical reliability appears to be a consistent strength across the evaluated projects, indicating this is a metric the company places considerable weight on from the start (Stage 0) when selecting their IoT solutions.

Overall Project Success: From this sample, P6 stands out as the project with the highest potential. This could likely be attributed to its success in other locations outside the EU. However, the strict requirements of data privacy regulations disqualify this project from potential implementation. The second highest, P7, was indeed the only project in this sample to complete the entire adoption process. Similarly, the lowest score for P3 is in line with D.1, where it is shown that P3, along with P4, was the first project to be stopped.

Table D. 3: Aggregate results of project evaluation sheets: ITAF Project Evaluation Metrics

P#	Technical Capability	Organizational Capability	Financial Capability	Performance Improvement	Implementation Process Impact Assessment	Technical Availability	Project Overall
P1	2,00	2,00	3,00	3,00	5,00	5,00	3,333333333
P2	4,00	1,00	3,00	4,00	5,00	5,00	3,666666667
P3	2,00	1,00	1,00	2,00	4,00	4,00	2,333333333
P4	3,00	1,00	2,00	5,00	3,00	5,00	3,166666667
P5	4,00	1,00	2,00	5,00	4,00	5,00	3,5
P6	5,00	1,00	5,00	5,00	5,00	5,00	4,333333333
P7	4,00	4,25	3,50	4,00	3,50	4,00	3,875
P8	3,5	3,00	3,50	3,00	2,00	3,50	3,083333333
P9	4,00	4,00	2,50	3,50	3,00	3,50	3,416666667
P10	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Acronyms: P – IoT project, N/A – not applicable

Note: Project 10 is marked N/A because it’s still too early in the adoption process to evaluate.