



**THE ROLE OF DIGITAL TWIN TECHNOLOGY
IN ENHANCING SUPPLY CHAIN RESILIENCE
AND SUSTAINABILITY**

A CASE STUDY OF AMAZON



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ABSTRACT

The growing complexity of the global supply chains has made the demand on the improvement of supply chain resilience and sustainability even more pressing, especially in large-scale e-commerce logistics networks. The recent world shocks and increasing demands on the environment have revealed structural weaknesses within the efficiency-focused supply chain designs, and the need to transform them through digitally contactable change has become evident. The use of digital twin technology combining real-time data, simulation, and predictive analytics has become one of the prospective technologies in enhancing operational visibility and strategic decision making. Nevertheless, there is a lack of empirical insights into the way in which digital twins can at once contribute to resilience and sustainability in massive logistics ecosystems.

This paper discusses the application of the digital twin technology by Amazon in enhancing the survival of its global supply chain, contributing to sustainability and minimizing carbon emissions in the logistic operations, and solving the implementation issues seen in large e-commerce settings. The methodology used was a qualitative case study, which incorporates the secondary data analysis and an interview with the experts. Thematic analysis was also utilized to determine the major trends associated with disruption management, scenario simulation, energy optimisation and strategic integration.

The results show that the digital twin systems contribute to resilience in terms of better real-time visibility, predictive disruption modelling, and quicker adaptive response process. Also, digital twins facilitate the sustainability goals and help to optimise the routes, monitor the energy, and reduce the carbon efforts. However, the problems of implementation remain such as complexity of data integration, large requirements in terms of technological investment, and management of change within an organisation.

The paper has added value to the body of knowledge by putting resilience and sustainability in a single digital twin paradigm and offering an empirical analysis of digital transformation in global e-commerce logistics. Managerially, the results provide strategic planning to companies that strive to use digital twins to become operational robust as well as environmental.

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TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

1.1 Background of the Study	1
1.2 Research Problem and Rationale	2
1.3 Research Aim and Objectives	3
1.3.1 Research Aim	3
1.3.2 Research Objective	3
1.4 Research Questions	3
1.5 Significance of the Study	4
1.5.1 Academic Significance.....	4
1.5.2 Managerial and Strategic Significance	5
1.5.3 Broader Policy and Societal Relevance	6
1.6 Scope and Limitations.....	6
1.6.1 Scope of the Study	6
1.6.2 Limitations of the Study.....	7
1.7 Structure of the Thesis	8

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction to Digital Twin Technology.....	10
2.2 Evolution and Definition of Digital Twins in Supply Chain Context.....	11
2.2.1 Conceptual Evolution.....	12
2.2.2 Concept of Supply Chain Context	12
2.2.3 Relevance to Amazon	13
2.3 The Concept of Supply Chain Resilience	14
2.4 Sustainability and Carbon Reduction in Global Supply Chains	16
2.5 Applications of Digital Twin Technology in Supply Chain Management	18
2.5.1 Real-Time Supply Chain Visibility and Monitoring	19
2.5.2 Disruption Simulation and Predictive Analytics.....	20
2.5.3 Inventory and Warehouse Optimisation.....	20
2.5.4 Transportation and Logistics Planning.....	21
2.5.5 Improving Sustainability and Reduction of Carbon	21
2.5.6 Supplier and Network Optimisation	22
2.6 The Role of Data Analytics, IoT, and AI in Digital Twin Systems	22

2.7 Digital Twins and Risk Management in Logistics Operations	24
2.8 Theoretical Framework	25
2.9 Research Gap and Conceptual Model.....	26

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Research Philosophy (Interpretivism / Pragmatism)	28
3.1.1 Interpretivism.....	28
3.1.2 Pragmatism	29
3.1.3 Combining Interpretivism and Pragmatism	29
3.1.4 Philosophical Alignment with Research Questions	29
3.2 Research Approach (Qualitative / Exploratory).....	30
3.2.1 Qualitative Approach	30
3.2.2 Descriptive Character of The Research	31
3.2.3 Inductive Reasoning.....	31
3.2.4 Rationale for the Chosen Approach	31
3.2.5 Connection with Research Questions	32
3.3 Research Design (Case Study of Amazon)	33
3.3.1 Case Study Strategy and Justification	33
3.3.2 Selection of Amazon as Case Company	33
3.3.3 Case Study Design and Unit of Analysis	34
3.3.4 Data Integration and Case Study Procedure	34
3.3.5 Advantages and Limitations of Case Study Design.....	35
3.4 Data Collection Methods	35
3.4.1 Primary Data Collection: Semi-Structured Interviews	36
3.4.2 Secondary Data Collection	36
3.4.3 Justification for Data Collection Methods	37
3.5 Sampling Strategy and Selection of Interviewees	37
3.5.1 Sampling Strategy	37
3.5.2 Target Participant Categories	38
3.5.3 Sample Size.....	38
3.5.4 Recruitment Process.....	39
3.5.5 Inclusion and Exclusion Criteria.....	39
3.6 Data Analysis Technique (Thematic Analysis)	40
3.6.1 Rationale for Choosing Thematic Analysis	41

3.6.2 Thematic Analysis Process	41
3.6.3 Integration of Secondary Data	42
3.6.4 Ensuring Analytical Rigor.....	42
3.7 Validity, Reliability, and Triangulation	42
3.7.1 Validity (Credibility).....	43
3.7.2 Reliability (Dependability)	43
3.7.3 Triangulation and Overall Trustworthiness.....	43
3.8 Ethical Considerations	44
3.8.1 Informed Consent.....	44
3.8.2 Confidentiality and Anonymity.....	45
3.8.3 Data Protection and Storage.....	45
3.8.4 Ethical Compliance	45
3.9 Limitations of the Research Methodology.....	45
3.9.1 Methodological Limitations.....	45
3.9.2 Data Collection Limitations.....	46
3.9.3 Generalisability and Scope	46
CHAPTER 4: FINDINGS AND ANALYSIS	
4.1 Overview of Amazon’s Global Supply Chain.....	47
4.2 Evidence of Digital Twin Applications at Amazon’s Supply Chain	49
4.3 Findings from Expert Interviews	50
4.3.1 Digital Twin Capabilities and Operational Visibility.....	51
4.3.2 Role of Digital Twins in Supply Chain Resilience	51
4.3.3 Contribution to Sustainability and Operational Efficiency.....	52
4.3.4 Challenges and Limitations of Digital Twin Implementation.....	52
4.3.5 Future Outlook and Strategic Implications	53
4.4 Discussion and Thematic Analysis	53
4.4.1 Theme 1: Digital Twin Capabilities and Supply Chain Visibility.....	54
4.4.2 Theme 2: Digital Twins and Supply Chain Resilience	54
4.4.3 Theme 3: Sustainability and Operational Trade-Offs	55
4.4.4 Theme 4: Implementation Challenges and Organisational Barriers	55
4.4.5 Synthesis of Themes	56
4.5 Cross-Analysis with Literature	56
4.5.1 Correlation with Literature on Supply Chain Resilience.....	56
4.5.2 Digital Twins and Sustainability in Relation to Existing Research	57

4.5.3 Implementation Challenges and Sociotechnical Perspectives	57
4.5.4 Strategic Implications and Dynamic Capabilities	57
4.5.5 Synthesis of Empirical and Theoretical Insights	58
4.6 Summary of Key Insights	58
CHAPTER 5: DISCUSSION	
5.1 Interpretation of Findings in Relation to Research Questions	60
5.1.1 Interpretation in Relation to Rq1: Digital Twins and Supply Chain Resilience	60
5.1.2 Interpretation in Relation to Rq2: Digital Twins and Sustainability Outcomes	61
5.1.3 Interpretation in Relation to Rq3: Challenges and Implementation Barriers	61
5.1.4 Overall Interpretation and Synthesis.....	62
5.2 Comparison with Existing Literature.....	62
5.2.1 Comparison with Literature on Supply Chain Resilience.....	64
5.2.2 Comparison with Literature on Sustainability	65
5.2.3 Comparison with Sociotechnical Perspectives	65
5.2.4 Comparison with Dynamic Capabilities Theory.....	65
5.2.5 Synthesis of Comparative Insights.....	66
5.3 Theoretical Implications	66
5.3.1 Contribution to Digital Twin Theory	67
5.3.2 Contribution to Supply Chain Resilience Theory	68
5.3.3 Contribution to Sustainability Theory	68
5.3.4 Contribution to Sociotechnical Systems Theory.....	69
5.3.5 Contribution to Dynamic Capabilities Theory.....	69
5.3.6 Synthesis of Theoretical Contributions.....	69
5.4 Managerial Implications	70
5.4.1 Enhancing Supply Chain Visibility and Decision-Making.....	70
5.4.2 Strengthening Supply Chain Resilience.....	70
5.4.3 Leveraging Digital Twins for Sustainability	71
5.4.4 Addressing Implementation Challenges	71
5.4.5 Strategic and Organisational Considerations	71
5.4.6 Summary of Managerial Implications	72
5.5 Revised Conceptual Framework.....	72
5.5.1 Key Contributions of the Revised Framework	73
5.5.2 Implications of the Framework.....	74
5.5.3 Dynamic Feedback Loops.....	74

5.5.4 Textual Representation of the Framework	75
5.5.5 Contribution of the Revised Framework.....	76
CHAPTER 6: CONCLUSION AND RECOMMENDATIONS	
6.1 Summary of the Research	78
6.2 Key Conclusions	79
6.3 Recommendations	81
6.3.1 Strategic and Operational Recommendations	82
6.3.2 Implementation and Organisational Recommendations	82
6.4 Future Research Directions	82
6.5 Reflections on the Research Process.....	84
REFERENCES.....	86

LIST OF FIGURES

Figure 1.1: Structure of the Thesis.....	9
Figure 2.1: Digital Twin Capability Layers in Supply Chain Management	23
Figure 2.2: Efficiency–Resilience Trade-Off and the Role of Digital Twin Systems	27
Figure 3.1: Research Methodology Framework	35
Figure 3.2: Interview Coding Framework	40
Figure 4.1: Thematic Structure of Findings	48
Figure 4.2: Architecture of Amazon’s Global Supply Chain with Digital Twin Integration	48
Figure 5.1: Digital Twin Influence on Sustainability Outcomes	63
Figure 5.2: Mechanism Through Which Digital Twins Enhance Supply Chain Resilience.....	67
Figure 5.3: Revised Conceptual Framework	72
Figure 5.4: Revised Conceptual Framework Linking Digital Twin Capabilities with Resilience and Sustainability Outcomes.....	75

LIST OF TABLES

Table 1.1: Alignment Between Research Aim, Objectives and Research Questions.....	4
Table 1.2: Scope Boundaries of the Study	7
Table 2.1: Comparative Definitions of Digital Twin Technology.....	14
Table 2.2: Enables Rapid Response to Disruptions	15
Table 2.3: Applications of Digital Twin Technology in Supply Chain Management	19
Table 3.1: Philosophical Alignment with Research Questions	30
Table 3.2: Justification for approach to research questions	32
Table 3.3: Alignment of Research Questions and Methodological Approaches.....	32
Table 3.4: Profile of Interview Participants	38
Table 3.5 Framework Based on Four Dimensions.....	44
Table 4.1: Summary of Emergent Themes from Expert Interviews	53
Table 5.1: Comparison of Empirical Findings with Existing Literature.....	64
Table 6.1: Summary of Key Contributions of the Study.....	79

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Over the last 20 years, global supply networks have changed very fast because of the digitalisation, globalisation, and the increase of e-commerce by several times. Business enterprises are becoming more intricate and interdependent chain of logistics across different continents, suppliers, distribution centres and modes of transportation. Although this global integration has made this more efficient and has lowered the costs of operation, there has been the exposure to disruption within the system (Christopher, 2016; Ivanov, 2021).

The recent past has revealed weaknesses in the world supply chains due to events such as COVID-19 pandemic, tensions between countries, and congestion in ports, as well as weather-related disruptions. Such disruptions pointed to the weaknesses of efficiency-based models and reiterated the significance of supply chain resilience, which is the ability to predict, absorb, respond to, and recover disruptions and ensure the disruption in operations (Christopher and Peck, 2004; Ivanov, 2020).

At the same time, the issues of sustainability have become more acute. The logistics and transportation processes also play a major role in carbon emissions in the world. There has been a growing pressure on large corporations therefore to lower the carbon footprints, to optimise energy consumption as well as shift to more environmentally responsible operations (Seuring and Müller, 2008).

Digital twin technology has come in as a potentially radical solution to these challenges. A digital twin is an active virtual simulated image of a real-world system combining real time data, sophisticated analytics, simulation models and predictions (Tao et al., 2019; Fuller et al., 2020). In the case of supply chains, digital twins can be used to promote real-time visibility, disruption modelling, demand forecasting, route optimisation, and scenario simulation (Ivanov and Dolgui, 2020).

Amazon has one of the most digitally integrated networks of supply chain in the world. Having large fulfilment centres, sortation hubs, transportation resources, and advanced analytics,

Amazon offers an interesting example to study the way in which the principles of digital twin can be used to contribute to the resilience and sustainability. Moreover, the company has publicly pledged some of the largest sustainability goals, such as carbon neutrality and renewable energy investments (Amazon, 2023).

The paper will hence examine the application of digital twin technology at Amazon to enhance the resilience of its global supply chain and assist in sustainability and carbon reduction.

1.2 RESEARCH PROBLEM AND RATIONALE

Although the topic of digital twin technology is becoming increasingly popular in academic and industry literature, there are still gaps in the research (Tao et al., 2019; Ivanov, 2020).

To begin with, much of the digital twin's studies are theoretical or simulation-based studies without empirical data based on big global networks in e-commerce. Second, current literature is frequently based on a study of operational efficiency and not on the resilience to real-world disruptions. Third, sustainability implications- especially carbon reduction- are often considered apart of resilience, which results in discontinuous analysis (Tao et al., 2019; Fuller et al., 2020; Ivanov, 2020).

It leads to insufficient combined empirical knowledge on the simultaneous availability of digital twin systems to supply chain resilience, sustainability and carbon reduction, and strategic decision-making in complex logistics ecosystems.

Despite the process of digital transformation of Amazon that is often referred to as the example of a digital-advanced organisation, the scholarly analysis of how digital twin opportunities can positively impact global supply chain resilience and sustainability in Amazon has not been developed.

As such, the research problem of this study is as follows:

Empirical knowledge on how Amazon applies the digital twin technology to improve supply chain resilience and sustainability is not exhaustive, and what challenges and opportunities are encountered in the implementation of such systems at scale.

Amazon was chosen as the centre of focus due to its distributed logistics network around the globe, high utilization of data analytics and automation capabilities, vulnerability to global disruptions, and high sustainability pledges to the population.

These attributes render Amazon an analytically endowed and strategically appealing case of interest.

1.3 RESEARCH AIM AND OBJECTIVES

1.3.1 RESEARCH AIM

The aim of this study is:

The research question is to discuss the application of digital twin technology to improve the resilience of the Amazon global supply chain, contribute to sustainability and carbon reduction and overcoming the implementation difficulties in the large-scale e-commerce logistics.

1.3.2 RESEARCH OBJECTIVES

In this goal, the following objectives are the ones sought in the study:

- To examine the application of the digital twin technology by Amazon in enhancing its supply chain resilience.
- The objective of the study is to test the hypothesis that digital twin systems can be used to enhance sustainability and carbon reduction in the logistics of Amazon.
- To find out the critical challenges and opportunities linked to the implementation of digital twin systems within logistics of large-scale e-commerce.
- To generalise research into a conceptual model between digital twin potential and resilience and sustainable performance.

All the objectives are directly connected with one or several research questions.

1.4 RESEARCH QUESTIONS

This study addresses the following research questions:

RQ1: How does Amazon use digital twin technology to improve the resilience of its global supply chain?

RQ2: In what ways do digital twins contribute to sustainability and carbon reduction in Amazon's logistics operations?

RQ3: What are the main challenges and opportunities in implementing digital twin systems in large-scale e-commerce logistics?

These research questions guide the literature review, methodology, data analysis, and discussion.

Table 1.1 illustrates the association between the research aim, objectives, and research questions to achieve conceptual clarity and methodological alignment of the study. This systematic mapping illustrates the way every objective builds up to the overall goal, and the research questions operationalise the objectives. This correspondence improves the internal consistency of the research and gives an analytical guide on the further chapters.

Research Aim	Research Objectives	Research Questions
To examine how Amazon uses digital twin technology to enhance resilience and sustainability in its global supply chain	Objective 1: Analyse digital twin use for resilience	RQ1
	Objective 2: Evaluate sustainability and carbon reduction	RQ2
	Objective 3: Identify challenges and opportunities in implementation	RQ3

Table 1.1: Alignment Between Research Aim, Objectives and Research Questions
(Source: Developed by the authors (2026))

Each research objective is clearly connected to a research question, as explained in Table 1.1, and there are no inconsistencies between the conceptual frame and the actual research. objective 1 and RQ1 cover the resilience aspect of the Amazon supply chain, objectivity 2 and RQ2 cover its sustainability and carbon reduction, and objectivity 3 and RQ3 cover the implementation issues and strategic possibilities. Such systematic correspondence ensures that data collection, analysis, and discussion are systematically related to the main purpose of the research.

1.5 SIGNIFICANCE OF THE STUDY

This study is important in both scholarly, managerial, and strategic levels.

1.5.1 ACADEMIC SIGNIFICANCE

The paper has several significant contributions to the dynamic literature on supply chain management digital transformation.

To begin with, because the concept of digital twin has been widely deliberated on in the manufacturing and engineering context, there is little empirical research on the application of this concept in the e-commerce logistics networks operated by large corporations. This study enhances the impact of digital twin scholarship to the sphere of digitally intensive retail logistics by narrowing down its scope to Amazon global supply chain (Tao et al., 2019).

Second, existing literature tends to distinguish a research stream of resilience and sustainability. The focus of the research on resilience is on the management of disruption, adaptability and mitigation of risks, compared to the sustainability research, which is on carbon reduction, energy efficiency and environmental responsibility. This paper combines both points of view in a single analytical framework and shows how digital twin features can assist in operational resiliency and environmental sustainability at the same time (Christopher and Peck, 2004).

Third, the study fills a gap in the research methodology. There is a lot of previous studies based on simulation modelling or conceptual theorisation. The current research presents qualitative empirical information based on interviews with experts, which adds practitioner-based theoretical discourses to the theoretical discussions.

Lastly, the synthesis of findings in the form of a conceptual framework contributes to the refinement of the existing literature in the field of dynamic capabilities and systems theory to show how digital twin systems are used as an enabling infrastructure to promote adaptive and sustainable supply chain transformation.

1.5.2 MANAGERIAL AND STRATEGIC SIGNIFICANCE

As a manager, one can use this study to take practical advice when investing in digital transformation efforts in organisations.

In the case of Amazon, the study presents the contribution of digital twin capabilities in:

- Increased real time visibility of logistics.
- Better predictive response and state simulation.
- Quick response and recovery in times of supply chain shocks.
- Better choice decision-making about energy consumption and routing optimisation.

To other large-scale e-commerce and logistic companies, the findings provide a guideline on:

- The business case of investing in digital twins.

- Skills needed by organisations to be effective in implementation.
- Efficiency, resilience and sustainability trade-offs.
- The most crucial technological and cultural obstacles that must be overcome.

As the rate of disruption and environmental control grows, it is strategically vital to know the twofold advantageous aspects of digital twin systems in long-term competitiveness.

1.5.3 BROADER POLICY AND SOCIETAL RELEVANCE

This research has wider societal implications other than organisational gains.

The logistics activities are also a significant source of greenhouse gases in the world. Provided that the digital twin technologies can be used to optimise the route, increase energy efficiency, and reduce carbon at scale, their utilisation can make a substantial contribution to the overall sustainability goals of the world.

Also, improving supply chain resilience makes a business, employee, and consumer more stable by minimizing economic vulnerability in times of global crises.

In this way, the research will contribute not only to academic discussion and corporate strategy, but also to general debates about the contentious topics of sustainable and resilient global supply networks.

1.6 SCOPE AND LIMITATIONS

Scopes and limitations stated clearly enhance credibility in the methodology and portray the level of academic maturity.

1.6.1 SCOPE OF THE STUDY

There are some deliberate parameters of this research.

To begin with, the research is a single in-depth case study of the global supply chain operations of Amazon. It is not aimed at comparing two or more firms but a closer contextual analysis of a highly digitalised logistics ecosystem.

Second, the paper focuses on the topic of digital twin technology in supply chains and logistics in particular. It does not look at digital twins in product design, manufacturing engineering and customer analytics beyond the field of logistics.

Third, there are two main performance dimensions used in the research:

- Supply chain resilience
- Sustainability and carbon mitigation.

The main analytical focus is not on financial performance, shareholder value, or technical quantitative measures of operations.

Fourth, the methodology is based on qualitative data, which is retrieved in the form of expert interviews and secondary sources. The aim here is to create interpretive information as opposed to statistically generalisable information.

1.6.2 LIMITATIONS OF THE STUDY

A few constraints should be taken into consideration.

- The single-case design does not allow generalisation to other industries or small firms.
- Proprietary internal information in Amazon is limited and hence may not be able to provide much operational transparency.
- The size of the expert interviews is small, with the participants having a great level of domain knowledge.
- The fast-paced technological change implies that the digital twin capabilities can keep on evolving even after the completion of the research.

These shortcomings are however complemented by the level of analysis, theoretical synthesis, and triangulation between the data of the interviews and the scholarly sources.

Consideration of such limitations improves the validity and the openness of the study.

It is necessary to clearly define analytical boundaries of the research, which is why Table 1.2 summarises what is part of the study and what is not.

Included in This Study	Excluded from This Study
Amazon global logistics network	Multi-company comparative analysis
Digital twins in supply chain operations	Digital twins in product design or manufacturing engineering
Supply chain resilience and sustainability	Financial performance modelling or shareholder value analysis
Qualitative expert interviews	Large-scale quantitative surveys

Table 1.2: Scope Boundaries of the Study
(Source: Developed by the authors (2026))

The study is specifically aimed at the logistics activities of Amazon in other countries and at the meeting point of digital twin technology and resilience and sustainability results as demonstrated in Table 1.2. Areas like multi-company comparison, financial modelling and large-scale quantitative surveys are not considered to sustain analytical depth and conceptual focus. This specificity will increase the methodological transparency and reinforce the coherence of the research design.

1.7 STRUCTURE OF THE THESIS

This thesis is written in a logical and progressive form to answer the research aim and questions exhaustively.

Chapter 1 provides the background of the research, statement of the problem, purpose and objectives of the research and the general outline of the thesis.

Chapter 2 gives an extensive literature review of digital twin technology, supply chain resilience, sustainability, and theoretical frameworks related to the topic. The chapter is concluded by acknowledging the existence of an obvious gap in research and the creation of a conceptual basis of the study.

Chapter 3 describes the research methodology. It describes the philosophical positioning, research design, case study method, data collection protocols and thematic analysis methodologies that were used to address the research questions.

Chapter 4 introduces the empirical results that were obtained based on the Amazon case study and interviews with the experts. The main themes are defined and discussed within the context of resilience, sustainability, and the issue of implementation.

Chapter 5 findings are discussed in connection with the literature available at the time and particular theoretical implications evaluated, managerial recommendations offered, and an overall conceptual framework that connects digital twin capabilities with the outcomes of resilience and sustainability.

Chapter 6 concludes the study with a summary of the main insights, a reflection on the contribution and limitations of the research and recommendations on the future research.

This is a logical flow that keeps the progression systematized and in line with the research questions.

The general outline of the thesis is a logical flow of the identification of the problem, theoretical background, empirical studies, and final synthesis. Figure 1.1 shows the structural flow of the research.

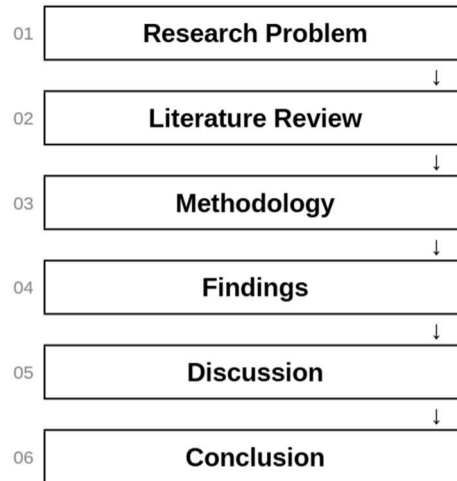


Figure 1.1: Structure of the Thesis
(Source: Developed by the authors (2026))

The research presented in Figure 1.1 could start with defining the problem and reviewing the relevant literature, then proceed to the methodology design and the results of the findings. Results and theoretical perspectives are combined in the discussion chapter, which results in conclusions and recommendations. This systematic sequence can provide analytical consistency and systematic correspondence with the research questions.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION TO DIGITAL TWIN TECHNOLOGY

The growing sophistication of the global supply chains and the startling pace of the digital transformation has compelled organizations to implement improved technologies to improve visibility, agility, and sustainability. Digital Twin (DT) technology has become one of these technologies and has proven to be a revolutionary solution that has served as a missing link between the physical and the digital world (Grieves, 2014; Tao et al., 2019).

A Digital Twin can be broadly referred to as a virtual representation of a tangible object, process or system that can be continuously monitored, simulated and optimized by means of data integration in real time (Grieves, 2014; Tao et al., 2019).

Digital twins were originally invented within the realm of aerospace engineering, but nowadays, they can be an effective tool in manufacturing, logistics, health care, and city planning. Digital twins are being used in supply chain management to help companies recreate a whole supply network on a computer and therefore be able to forecast disruption, streamline operations and test their strategic choices prior to accommodating them in the real world (Ivanov & Dolgui, 2020).

A digital twin is a combination of various digital technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), Cloud Computing, and Big Data Analytics, to receive, process, and analyse real-time physical asset or system data. The interconnectivity forms a closed-loop feedback system, in which the digital model is continuously learning and adjusting based on the physical one, thus improving the efficiency of operations and strategic decision-making (Fuller et al., 2020).

In the case of global companies like Amazon, digital twins have the potential to offer real-time visibility of logistics networks and simulate the effect of what-ifs (e.g., route disruptions, demand variations) and aid proactive decision-making to enhance supply chain resiliency and environmental performance.

In a world that is becoming more volatile e.g. in terms of pandemics, geopolitics, and environmental issues, real-time modelling, prediction, and adaptation have become a crucial competitive advantage (Ivanov, 2021).

Such inclusion of digital twins into supply chain management is therefore not only a technological innovation but also a strategic change to data-oriented and sustainable operations.

The subsequent parts consider the conceptual and operational history of the digital twin technology, especially concerning the supply chain, and how it supports resilience and sustainability in the global business.

2.2 EVOLUTION AND DEFINITION OF DIGITAL TWINS IN SUPPLY CHAIN CONTEXT

The idea of a Digital Twin dates to the early 2000s, when it was suggested by Dr. Michael Grieves at the University of Michigan in one of the Product Lifecycle Management (PLM) contexts.

Grieves (2002) suggested that all tangible products could be accompanied by a virtual one a so-called digital twin that replicated its behaviour and performance through its lifecycle. This concept was later embraced and developed by NASA to aid in monitoring spacecrafts and simulations of missions (Glaessgen & Stargel, 2012), which was a milestone towards putting the concept into actual practice on a large-scale involving engineering.

The digital twins in the past decade have evolved in a broad way beyond manufacturing and design of products. Due to the advent of Industry 4.0 and the Internet of Things (IoT), digital twins have also been getting more data-filled and dynamic, incorporating real-time information provided by sensors, enterprise software, and analytics software (Tao et al., 2018).

This has enabled them to become very relevant in the supply chain implementations where real-time visibility, predictive insights and adaptability are essential in dealing with global complexity and risk.

2.2.1 CONCEPTUAL EVOLUTION

First, digital twins concentrated on the asset-level simulating, e.g., simulating the work of machinery or a product. But with the progress in connectivity and computational capacity, they have now been applied to process level applications and to system level applications (Tao et al., 2019; Fuller et al., 2020).

In the present day, digital twins may represent the whole supply chain ecosystem; suppliers and warehouses, transport paths and customer communication (Kamble et al., 2021). Such an evolution is an example of the transformation of fixed digital models to systems that are intelligent and self-learning and can make decisions in real-time.

Digital twins within the supply chain setting generally work using three combined layers (Tao et al., 2019):

- **Physical Layer:** The real equipment, logistics infrastructure, and equipment that creates data with the use of IoT devices and senses.
- **Digital Layer:** The virtual representation of the environment or the environment where data is being stored, processed and analysed.
- **Connection Layer:** The data communication and feedback system which allows synchronizing the physical and digital systems.

With this networked system, digital twins enable companies to foresee possible interruptions, analyse the situation, and take corrective measures virtually before investing in the real world.

2.2.2 CONCEPTS OF SUPPLY CHAIN CONTEXT

Other definitions differ according to field, but scholars tend to highlight that digital twins are dynamic and two-way.

As an example, a digital twin is defined by Tao et al. (2018) as a digital representation of a physical object that is constantly updated and can communicate with each other in real-time by exchanging data.

Negri et al. (2017) extend this to simulation models that are used to reproduce the behaviour of physical systems and give predictive and prescriptive information.

Digital twins are becoming considered as strategic enablers, as opposed to operational tools, in supply chain management.

Ivanov and Dolgui (2020) note that digital twins can be used to promote supply chain resilience by facilitating data-driven resiliency decisions during disruptions, supporting the interdependency visibility, and enhancing the speed of scenario modelling.

They help achieve sustainability as well, by ensuring resource efficiency, lowering waste and emissions by planning their logistics and energy consumption better (Kamble et al., 2021; Waller and Fawcett, 2022).

Although the literature is becoming more unified on the definition of digital twins as dynamic data-driven virtual representations of real-world systems (Tao et al., 2019; Fuller et al., 2020), the conceptual ambiguity on the breadth and the level of maturity of digital twins remains to this day. Other researchers also make the distinction between simple digital models, digital shadows, and entirely integrated digital twins (Kritzinger et al., 2018), maintaining that most digital twins used in industries do not fit the definition of being two-way and real-time synchronized. Others have a more liberal, functional definition, meaning one that focuses on the ability to simulate (rather than the technical architecture) (Negri et al., 2017). This divergence in definition is an indication that the empirical statement about the impact of a digital twin will have to be construed with caution, at least when considering the existence of the latter in supply chain-related scenarios.

2.2.3 RELEVANCE TO AMAZON

The development of digital twin technology in the situation with Amazon is also closely connected with its goal of the pursuit of operational excellence and the leadership in the field of sustainability (Tao et al., 2019; Fuller et al., 2020).

Amazon can model intricate systems and make its logistics networks, fulfilment centres, and transportation routes through digital reflection to achieve better efficiency, predict demand, and analyse sustainable policies, including mapping routes to reduce carbon emissions (Ivanov and Dolgui, 2020).

This type of application illustrates why digital twins have become more than mere conceptual tools to operational digital ecosystems creating organizational resilience within the global supply chain (Waller and Fawcett, 2022).

Nevertheless, these benefits do not inevitably lead to the effective implementation of the digital twin systems in large-scale supply chains because of the issues of integrating data and a high level of infrastructure demands (Fuller et al., 2020).

Digital twin technology is defined differently and conceptualised differently in the literature based on the field of application. To indicate these distinctions and determine some common points, Table 2.1 captures major definitions and areas of their focus.

Author	Year	Definition Focus	Key Elements	Context
Tao et al.	2019	Real-time virtual representation	Data integration, bidirectional sync	Manufacturing
Kritzinger et al.	2018	Model–Shadow–Twin hierarchy	Maturity levels	Industrial systems
Fuller et al.	2020	Digital lifecycle integration	Predictive capability	Smart systems
Ivanov & Dolgui	2020	Simulation for supply chains	Disruption modelling	Logistics

Table 2.1: Comparative Definitions of Digital Twin Technology

(Source: Compiled by the authors from Ivanov & Dolgui (2020), Tao et al. (2019), and related literature)

As it can be seen in Table 2.1, although there is a consensus on the issue of integrating real-time data and virtual representation, major disparities still exist in the extent, maturity levels, and the context of implementation. This difference in definition supports the notion that caution should be exercised in analysing the application of digital twins to intricate supply chain management contexts like Amazon international network.

2.3 THE CONCEPT OF SUPPLY CHAIN RESILIENCE

The concept of supply chain resilience has become a burning issue due to the rising rates of disruptions and their intensity to global logistics chains. Historically, the use of supply chains was mainly based on efficiency and minimisation of costs, but the current scenarios have shown that this is not effective in very uncertain settings. The broad definition of supply chain resilience is the capability of a supply chain to predict, react, and recover the impact of any disruption without the continuity of the functions and performance (Christopher and Peck, 2004; Ivanov, 2020).

Various global crises have led to the increasing significance of resilience, such as the COVID-19 crisis, geopolitical tensions, trade limitations, and climate-related incidents. Such upheavals have revealed the structural weaknesses in the global supply chains especially those that are lean and just-in-time based supply chains. As it was shown in the case of the COVID-19 crisis, highly optimised supply chains did not necessarily have the flexibility to absorb shocks, which led to severe delays, shortages, and breakdown of the operations (Ivanov, 2020). As a result, resilience as a strategic capability has become a key focus of organisations as opposed to a response to a situation.

There are many dimensions of supply chain resilience such as flexibility, adaptability, visibility, and redundancy. Flexibility means adapting to alterations in operations and adaptability encompasses long-term structural changes to respond to the emerging risks. Visibility creates real-time visibility and information exchange throughout the supply chain networks, enabling organisations to identify disruptions in time and effectively respond. Redundancy like holding up buffer stock or alternative suppliers will offer extra capacity to absorb shocks but will raise operational costs (Christopher and Peck, 2004).

Table 2.2 gives an overview of the main aspects of supply chain resilience and the role they play in disruption management.

Dimension	Description	Contribution to Resilience
Flexibility	Ability to adjust operations in response to changes	Enables rapid response to disruptions
Adaptability	Capacity to restructure supply chain over time	Supports long-term resilience
Visibility	Real-time monitoring of supply chain activities	Improves early detection of disruptions
Redundancy	Availability of backup resources (e.g., suppliers, stock)	Provides buffer against disruptions

Table2.2: Enables rapid response to disruptions

(Source: Compiled by the authors from Christopher & Peck (2004), Ivanov (2020), and related literature)

Supply chain resilience is a multidimensional construct which incorporates operational flexibility, strategic adaptability, real-time visibility and structural redundancy as shown in

Table 2.2. All these dimensions allow organisations to predict, react and overcome disruptions better. There tend however to be trade-offs when implementing these capabilities. Although redundancy and flexibility lead to resilience, these are likely to lower efficiency and raise costs, posing a concession between efficiency-oriented and resilience-oriented supply chain strategies (Christopher and Peck, 2004).

To address them, digital technologies have become the subject of growing discussion as providers of supply chain resilience. High-tech data analytics, real-time monitoring tools, and predictive modelling tools enable organisations to become more visible, predict disruptions, and simulate alternative situations. Specifically, the digital twin technology has come out as a promising option as it offers a dynamic and data-driven model of the supply chain operations (Ivanov and Dolgui, 2020). Digital twins allow organisations to be proactive in handling disruption and making better decisions in circumstances of uncertainty through real-time data integration and simulation of scenarios.

Altogether, supply chain resilience is a paradigmatic change between efficiency-driven supply chain design and dynamic and responsive forms of operations. With the ever-growing uncertainty in global supply chains, the incorporation of digital twin is projected to be an essential factor in supply chain management in increasing resilience and improving the supply chain management practices to be more sustainable and responsive.

2.4 SUSTAINABILITY AND CARBON REDUCTION IN GLOBAL SUPPLY CHAINS

Supply chain sustainability is the relationship between operation decision making and sustainability factors of the environment, society, and the economy to minimize adverse effects on the environment and society. Two of the dimensions, carbon reduction and environmental responsibility, have become the leading ones as the international regulation has become stricter, the corporate ESG demands have become more significant, and the pressure of stakeholders grows. Global supply chains, particularly those that are dependent upon international transport, production and logistics that are resource-intensive, constitute a substantial fraction of global greenhouse gas (GHG) emissions- sometimes up to 70-90 percent of a firm total carbon footprint (Seuring and Müller, 2008; Sarkis, 2012).

Conventional supply chain management concentrated greatly on low-cost procurement and efficiency optimization and did not emphasize on environmental impact such as energy use,

waste materials and emissions. Sustainability is however regarded as a strategic must. One of the factors that organisations need to strike a balance between is operational performance and environmental stewardship to ensure that they are compliant, competitive and socially responsible (Seuring and Müller, 2008).

There are various approaches to carbon reduction in supply chains, which include route optimisation, use of energy-saving transport, circular economy strategies, responsible sourcing technologies, minimisation of waste, increased forecasting to reduce overproduction, and the use of renewable energy in factories and warehouses. Life Cycle Assessment (LCA) and carbon-accounting approaches are also being incorporated by many firms to measure and trace the emissions throughout the supply chain, starting at the extraction of raw materials, all the way to disposal at the end of life (Sarkis, 2012; Waller and Fawcett, 2022).

Digital technologies have turned out to be important initiators of sustainable supply chains. Blockchain, IoT sensors, AI-driven optimisation models, and digital twins are some of the tools used to enable firms to measure real-time emissions, enhance transparency and isolate inefficiencies. Digital twins, specifically, can provide a revolutionary method whereby the carbon effects are modelled and simulated prior to actual decisions related to operations being implemented. An example of such a digital twin of a logistics network can be used to compare transportation modes, simulate route variations, test inventory placement and recommend the minimum-emission configuration. This assists in the planning of strategic sustainability and in day-to-day operational decision making (Waller and Fawcett, 2022; Tao et al., 2019).

Additionally, the international sustainability systems, such as the Paris Agreement, Science-based Targets (SBTi), and net-zero promises, are compelling organisations to follow more stringent carbon-cutting approach. Consumers and stockholders are also seeking traces of sustainability in their business, and carbon efficiency is becoming the defining factor of business sustainability in the long run and market worth (Ivanov and Dolgui, 2020; Tao et al., 2019).

In this way, sustainability and carbon reduction have transformed into mandatory activities to the current supply chain management. As a result of the growing environmental demands and technological changes, companies are currently considering digital technologies to build a more sustainable, more efficient, and transparent global supply network, using digital twins to do it. Such technologies help organisations not just cut emissions, but also to innovate and

reshape their supply chain practices in a new, more circular, long-term resilient and environmentally excellent form (Sarkis, 2012).

Although the idea of sustainability is gradually becoming a part of the supply chain discussions, there are scholars who consider that the environmental initiatives are commonly inspired by reputational or regulatory factors instead of internal strategic improvement (Seuring & Muller, 2008). It casts doubt on whether digital technologies and digital twins have a real impact on sustainability practices or are used, first, to improve reporting transparency. Thus, evaluation of the real sustainability effect of digital twin application should be undertaken with scrutiny of actual ESG promises.

In this regard, digital twin technology offers a scientific solution to balance the operational efficiency and sustainability goals with data, which makes it an important instrument to contemporary supply chain management.

2.5 APPLICATIONS OF DIGITAL TWIN TECHNOLOGY IN SUPPLY CHAIN MANAGEMENT

The rising popularity of digital twin technology in supply chain management has been attributed to replication, simulation, and optimisation capabilities of the complex logistics environment in real-time. With the increased interconnectedness and vulnerability of global supply chains to disruptions, the digital twins provide organisations with an influential decision-support tool basing it upon the data-driven insights. The sections below discuss the major uses of digital twins in various areas of the supply chain, and how the technology has improved efficiency of operations, resiliency, and sustainability (Tao et al., 2019; Fuller et al., 2020).

Use of digital twin in supply chain management cuts across various areas of operation. These applications have been classified in Table 2.3 and their anticipated benefits listed.

Application Area	Purpose	Expected Benefit
Demand Simulation	Forecasting	Reduced stockouts
Route Optimization	Transport efficiency	Lower emissions
Facility Modelling	Capacity planning	Reduced congestion
Risk Scenario Testing	Disruption analysis	Faster recovery

Table 2.3: Applications of Digital Twin Technology in Supply Chain Management
(Source: Compiled by the authors from Geissdoerfer et al. (2017), Kamble et al. (2020), and related literature)

According to Table 2.3, digital twins are no longer limited to basic monitoring capabilities, but they are now increasingly powered by predictive modelling, optimisation, and risk simulation. These strengths are especially applicable to high-speed e-commerce supply chains, where the operational agility happens to be essential (Ivanov and Dolgui, 2020).

2.5.1 REAL-TIME SUPPLY CHAIN VISIBILITY AND MONITORING

One of the most essential uses of digital twins is the establishment of end-to-end visibility of supply chains, which can help overcome the long-standing issues of incoherence in information, transparency and insufficient visibility among partners, and irregular flow of data (Ivanov and Dolgui, 2020). Digital twins can give a single, synchronized digital representation of supply chain operations by incorporating data on IoT devices, RFID tags, warehouse management systems, transportation management systems, supplier platforms, and customer interfaces (Tao et al., 2019; Waller and Fawcett, 2022).

This real time visibility helps organisations to keep track of:

- Availability and location of inventory.
- Processing and fulfilment of order time.
- Status in the transportation and approximate time of delivery.
- Warehouse automation systems and machine performance.
- Lead times and compliance of suppliers and service levels.

With this visibility, there is less uncertainty, increased accountability between partners in the supply chain and early identification of bottlenecks. To track millions of SKUs, optimise the

work of fulfilment centres, and allocate resources dynamically depending on the customer demand patterns, companies such as Amazon rely on the real-time digital forecasting models (Ivanov and Dolgui, 2020).

2.5.2 DISRUPTION SIMULATION AND PREDICTIVE ANALYTICS

Among the strongest capabilities of digital twin models, predictive and prescriptive analytics make it possible to test complex situations without interfering with the real activities (Ivanov, 2020; Ivanov and Dolgui, 2020). Examples of risks that can be simulated by digital twins include:

- Natural disasters
- Delays or ports closure due to transportation.
- Supplier failures
- Peak demand (e.g. Black Friday, holiday seasons)
- Disruptions in the political and regulatory environment.
- Malfunctioning of machines and failure to maintain them.

The digital twins use machine learning and past data trends to produce the so-called what-if analyses, which assist organisations in estimating the repercussions of disruption and the effectiveness of alternative strategies. This is a direct positive effect of supply chain resilience as the firm can no longer solve problems reactively but mitigate risks proactively (Tao et al., 2019; Ivanov, 2020)

Indicatively, Amazon has intensively relied on simulation models to forecast the impact of high-volume events to ensure its global logistics infrastructure is also capable of scaling effectively during peak periods (Amazon, 2023).

2.5.3 INVENTORY AND WAREHOUSE OPTIMISATION

Digital twins have reinvented warehousing through the capability to model warehouse layouts, distribution of labour, robotics, storage, and material-handling operations (Tao et al., 2019).

They allow firms to:

- Maximise picking slotting strategies
- Alters the warehouse design but does not move anything.
- Simulations of human worker-autonomous robot interaction.
- Examine storage policies i.e. FIFO/LIFO.

- Minimize aisle and loading areas congestion.
- Enhance the utilisation of space and energy efficiency.

This would provide a zero-risk environment, where the operational improvements would be virtually tested and then implemented (Fuller et al., 2020). To enable the company to cut down the fulfilment times without compromising efficiency and safety, the fulfilment centres of Amazon are increasingly dependent on digital twin simulations that ensure that Kiva robots, human pickers, and sorting systems interact in the most efficient way possible (Amazon, 2023).

2.5.4 TRANSPORTATION AND LOGISTICS PLANNING

Digital twins can be applied to transport networks, routing, and fleet management within the logistics operations (Ivanov and Dolgui, 2020). Applications include:

- The real-time traffic, weather, and road conditions allow optimisation of delivery routes.
- Establishing suitable fleet utilisation and allocation of assets.
- Multimodal transport (air, sea, road, rail): simulation.
- Improving the performance of last-mile delivery.
- Modelling cross border customs delays and regulatory barriers.
- Predicting road emissions and fuel usage.

Digital twins enable organisations to dynamically adjust their logistics planning based on the dynamic conditions (Tao et al., 2019; Waller and Fawcett, 2022). In case of large-scale logistics operators, such as Amazon, a capacity to test routing plans virtually or understand the effect of new delivery hubs will add a lot of value to the cost-reduction, reliability, and sustainability (Amazon, 2023).

2.5.5 IMPROVING SUSTAINABILITY AND REDUCTION OF CARBON

Sustainability is now a strategic focus of global supply chains, and digital twins are also a key to making it possible to operate more environmentally efficiently (Seuring and Müller, 2008; Sarkis, 2012). Digital twins facilitate organisations to monitor and model:

- Transport mode emissions of carbon.
- Energy usage in warehouses.
- Effects of change in packaging.
- Waste materials of production and distribution.

- Logistics infrastructure use of renewable energy.
- Emissions in product life cycle.

The way to achieve this is by developing a digital model of sustainability metrics in real time, enabling organisations to pre-test the effect of operational decisions on the environment. As an example, the Amazon Shipment Zero program is based on considerable digital modelling and forecasting solutions to minimise emissions and optimise the delivery pathways (Tao et al., 2019).

2.5.6 SUPPLIER AND NETWORK OPTIMISATION

Digital twins can model an entire supply chain network, which offers information about supplier dependencies, global distribution flows, and strategic vulnerabilities (Ivanov and Dolgui, 2020). With such network models, companies can:

- Assess supplier potential and risk.
- Map multi-tier supply networks (Tier 2 and Tier 3 suppliers)
- Model some alternate such as nearshoring or supplier diversification.
- Test network expansion policies (e.g. new fulfilment centres or hubs)
- Evaluate financial reconfiguration of network.
- Enhance sourcing decisions and predictability of lead-time.

This modelling on a network level promotes the development of more resilient and adaptable supply chains and strategic decision-making. Complex global networks, like Amazon, are some of the companies that gain out of these digital twins to achieve continuity of suppliers, less dependency risk and end-to-end resilience (Ivanov, 2020; Fuller et al., 2020).

2.6 THE ROLE OF DATA ANALYTICS, IOT AND AI IN THE DIGITAL TWIN SYSTEMS

Digital twin systems can only function within the framework of a technological ecosystem, which is made possible and maintained through Internet of Things (IoT) devices, sophisticated data analytics, and artificial intelligence (AI). All these technologies enable real time data capture, processing, simulation and predictive decision-making environment in supply chains (Ivanov, 2020; Fuller et al., 2020).

IoT technologies provide a basis of the digital twin system through the constant possibility of data collection of physical objects, i.e., equipment of the warehouse, transport, storage units, energy facilities. Real-time operational data is sent by sensors and related devices, thus enabling the virtual model to respond to the present condition of physical processes (Tao et al., 2019). IoT integration is essential in the global supply chains like Amazon in which the scale of operations is high, and the distribution of operations is distributed across geographical locations.

Data analytics has been at the centre of converting raw functioning information into actionable information. Descriptive analytics helps to provide a real-time view, whereas predictive and prescriptive analytics allow one to make predictions, maximize, and model scenarios (Ivanov and Dolgui, 2020). Analytics tools in digital twin environments enable organisations to model failure points, experiment with alternative logistics routes, optimise throughput in the warehouse, and test possible strategies of reallocating inventory before it can be put into effect.

The conceptualisation of the architectural richness of digital twin system in terms of supply chain management is conceptualised in Figure 2.1, a layered capability framework.

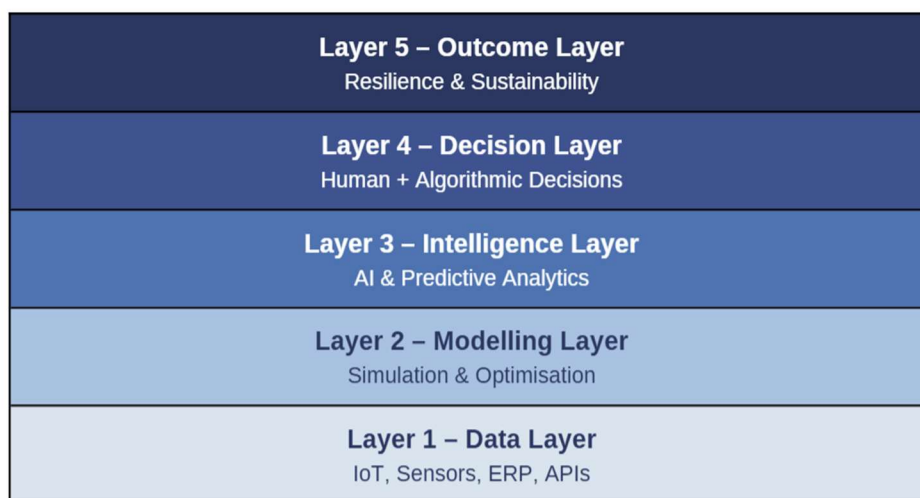


Figure 2.1: Digital Twin Capability Layers in Supply Chain Management
 (Source: Adapted by the authors from Tao et al. (2019) and Ivanov & Dolgui (2020))

The framework has shown that the foundational data infrastructures facilitate the higher-order modelling and intelligence levels, which eventually help in strategic decision-making and performance outcomes with respect to resilience and sustainability (Tao et al., 2019; Ivanov and Dolgui, 2020).

The next feature of AI technology is that it will improve the functionality of digital twins through adaptive learning and autonomous optimisation. The machine learning algorithms can identify trends in previous demand variations, uncovering unproductive transport networks, and optimizing predictors models. Nonetheless, even though the integration of AI can enhance the accuracy of predictions, there are the issues of the bias in the data, the lack of transparency in the model, and the excessive dependence on algorithmic decision-making. Several researchers warn that participatory approaches needed to supplement algorithm-based systems to prevent unforeseen or undesirable operational or ethical implications (Waller and Fawcett, 2013).

The complexity of implementation is also a big challenge even though there is a technological promise. The challenges of the integration of heterogeneous data sources into multi-tier global supply chains demand high interoperability, and cybersecurity resilience. This means that the success of digital twins is dependent not just on the level of technological advancement but also on governance frameworks, information quality control, and inter-functional orientation (Fuller et al., 2020).

Therefore, digital twins are to be thought of not as simulation tools alone but as socio-technical systems that are placed within the framework of a larger strategy of digital transformation.

2.7 DIGITAL TWINS AND RISK MANAGEMENT IN LOGISTICS OPERATIONS

The significance of risk management in global supply chains has become extremely relevant within the scope of the big disruptions, particularly the pandemics, the geopolitical instabilities, and the transport bottlenecks. The concept of digital twins is actively used to consider the opportunities of proactive and predictive risk management in logistics networks (Ivanov, 2020).

Conventional risk management techniques tend to be reactive in nature such as buffer inventory, multiple sourcing and contingency contracts (Christopher and Peck, 2004; Ivanov, 2020). Although some of them are effective to some extent, they can be added to the cost of operation and efficiency. Another alternative is the digital twin systems that allow real-time monitoring and stress-testing of the logistics networks.

Digital twins can simulate the effects of supplier failure, facility shutdowns, port congestion, or transportation delays using scenario simulating. This can enable organisations to review

alternative routing plans, re-blandishment of inventory, and dynamically plan the capacity (Ivanov, 2020; Ivanov and Dolgui, 2020). Digital twins supply chain make resilience-by-design possible by simulating predictability instead of being expensive through redundancy.

Nonetheless, practical evidence is not consistent. Although modelling studies have high theoretical potential, there are challenges with scaling to a real-world context. Simulation can be weakened by inaccurate upstream data; when visibility at the supplier level is low, digital twins do not work. Moreover, complicated behavioural variables e.g. labour shortages or regulatory changes are not easy to model accurately (Fuller et al., 2020).

Thus, digital twins can increase visibility and help in simulations, but they must be considered as aid offers but not as all-purpose risk avoidance tools.

2.8 THEORETICAL FRAMEWORK

In the present study, three theoretical perspectives have been used to supplement one another namely Systems Theory, the Resource-Based View (RBV) and the Dynamic Capabilities Framework.

Using the Systems Theory, supply chains are perceived as interdependent and connected networks and not as separate functional units (Von Bertalanffy, 1968; Ivanov, 2020). Digital twins are very much aligned to that of the systems thinking, in that it offers a comprehensive view of the supply chain as a whole ecosystem. This theoretical perspective focuses on feedback loop, interdependency and non-linear impact - features that are largely applicable to global e-commerce networks.

According to the Resource-Based View (Barney, 1991; Waller and Fawcett, 2022), one of the causes of sustained competitive advantage is the existence of value, rare, inimitable, and non-substitutable resources. Digital twin capabilities such as proprietary algorithms, integrated data infrastructure and predictive modelling systems can be part of the strategic resource under this framework. The RBV is however not sufficient in capturing the dynamic adjustment needed in a volatile environment.

Hence, it is complemented by the Dynamic Capabilities Framework (Teece, 2007; Ivanov and Dolgui, 2020). It stresses how the firm can feel, grab and rearrange resources as a response to the change in the environment. Digital twin's systems facilitate sensing (real time visibility), seizing (data informed decisions) and reconfiguring (adaptive operations). This theoretical

integration allows realizing the ultimate picture of the contribution of digital twins to resilience and sustainability achievements.

Taken together, these frameworks offer the multi-dimensional basis of the study of the digital twin practices at Amazon in the context of its global supply chain (Tao et al., 2019).

2.9 RESEARCH GAP AND CONCEPTUAL MODEL

Supply chain resilience and sustainability as independent fields of the supply chain management have been discussed in the existing literature abundantly, along with digital twin technology. The main topic of discussion of digital twins is data integration in real-time, simulation, predictive analytics, and the study of resilience is the issue of disruption management and adaptability. Equally, sustainability research is focusing on environmental performance and carbon cutting plans. Nevertheless, these domains tend to be considered separately, which restricts a comprehensive approach to their interaction in the context of the complex supply chains (Tao et al., 2019; Ivanov, 2020).

Although the topic of digital twin is gaining traction, no integrated empirical studies have focused on how digital twins can boost resilience and sustainability at the same time, especially in massive logistical spaces. The available research is mostly theoretical, and much attention has not been on practical application in complex and data-driven supply chains. The latter gap is particularly apparent when it comes to large e-commerce organisations like Amazon, in which the complexity of operations and the global flow of communication pose special challenges (Fuller et al., 2020; Ivanov and Dolgui, 2020).

This paper fills this gap by discussing how Amazon can leverage the power of digital twin technology to enhance supply chain resilience, sustainability and carbon reduction, and handle implementation issues in the global logistics network.

To represent the relations found in the literature, the conceptual framework of this study is depicted in Figure 2.2.

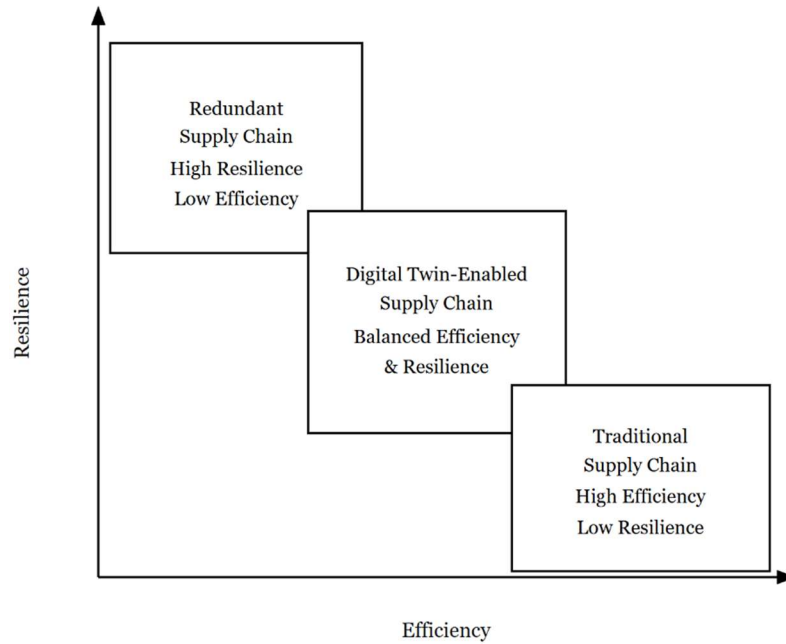


Figure 2.2: Efficiency–Resilience Trade-Off and the Role of Digital Twin Systems

(Source: Compiled by the authors from Christopher & Peck (2004), Ivanov (2020), and related literature)

Digital twin abilities, provided by real-time visibility, simulation, and predictive analytics as illustrated in Figure 2.2, can increase the resilience of a supply chain by providing better response and decision-making during disruptions. The resultant resilience capabilities in turn deliver sustainability outcomes in terms of increased resource efficiency and lower emissions. The framework identifies the mutual linkage between contemporary supply chains and the digital transformation, resilience, and sustainability.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 RESEARCH PHILOSOPHY (INTERPRETIVISM / PRAGMATISM)

Research philosophy can be defined as beliefs and assumptions of the nature of reality (ontology) and the production of knowledge (epistemology) that steer the research design, data collection and analysis procedures (Saunders et al., 2019). Philosophy is of critical importance in aspects of bringing the objectives of the research, the methodology and interpretation of results into line with the objectives of the research.

The proposed study takes a more philosophical position; it is based on interpretivism, with elements of pragmatism that complement one another to help understand that digital twin technology is a complex phenomenon when it concerns global supply chains.

3.1.1 INTERPRETIVISM

The assumption that the social construction of reality exists and interpreting the reality is done through the subjective meanings and experiences of the individuals forms the foundation of interpretivism (Bryman and Bell, 2015). Contrary to the positivist methods that lay emphasis on objective measurement, the interpretivism method is concerned with issues of how people make sense and interpret complex phenomena.

Within the framework of this research, interpretivism is specifically suitable because it can be used to investigate the views of experts regarding the role of digital twin technology in ensuring supply chain resilience and sustainability. These are necessarily multi-dimensional phenomena which concern the dimensions of technology, organisations and strategic dimensions which can not be represented solely based on quantitative measurement.

Taking an interpretivist position, this study aims to know how and why digital twins are conceived as value-creating in the supply chain business, as opposed to evaluating their quantifiable consequences. This is in line with the qualitative nature of the research and the discovery of subtleties of the expert interviews.

3.1.2 PRAGMATISM

Pragmatism is a complement to interpretivism because it focuses on the practical usefulness of knowledge and how it can be applied to practical issues (Creswell and Plano Clark, 2018). Practically, research is evaluated based on its utility and the capacity to give practical results.

Pragmatism does not only make the findings relevant in the context of this study but the findings should also make sense to practitioners in supply chain management and digital transformation. Due to the practical nature of the study, which will concentrate on the logistics activities at Amazon, the pragmatic approach justifies the combination of various sources of data, such as scholarly articles, reports in the industry, and opinions of experts.

Besides, pragmatism makes a case study method appropriate, since it allows exploring digital twin's usage as an application in a real-life organisational setting, creating knowledge that could inform academic knowledge as well as managerial practice.

3.1.3 COMBINING INTERPRETIVISM AND PRAGMATISM

The blending of interpretivism and pragmatism offers a moderate philosophical basis to this study. Interpretivism allows studying the subjective experience and understanding the circumstances in a deeper way, whereas pragmatism makes sure that the results have a practical meaning and applicability.

This combination is especially appropriate to research digital twin, which is located at the border of technological innovation, organisational strategy and sustainability. Although the interpretivism approach helps in creating the meaning of digital twins as perceived and implemented, pragmatism will make the research lead to actionable insights to enhance the supply chain resilience and sustainability.

3.1.4 PHILOSOPHICAL ALIGNMENT WITH RESEARCH QUESTIONS

Table 3.1 provides coherence between the research questions and respective philosophical perspectives to guarantee that there is consistency between the research philosophy and the study objectives.

Research Question	Philosophical Alignment
How does Amazon use digital twin technology to improve the resilience of its global supply chain?	Interpretivism - investigating the views and perceptions of resilience mechanisms held by experts.
In what ways do digital twins contribute to sustainability and carbon reduction in Amazon's logistics operations?	Both - interpretivism (perceived sustainability impact) and pragmatism (practical outcomes).
What are the main challenges and opportunities in implementing digital twin systems in large-scale e-commerce logistics?	Pragmatism - finding practical insights and application to the executives.

Table 3.1: Philosophical Alignment with Research Questions

(Source: Developed by the authors (2026))

The research questions are in line with the interpretivism, and pragmatic perspectives as seen in Table 3.1. The interpretivism approach will be especially useful in examining the perceptions of experts and the extent to which digital twins will improve supply chain resilience and sustainability. Meanwhile, pragmatism encourages the definition of practical implications, challenges, and opportunities connected to the implementation of digital twin systems on the large-scale logistics settings. This correspondence helps in equipping this study with a level of theoretical richness and practicality.

3.2 RESEARCH APPROACH (QUALITATIVE / EXPLORATORY)

In the research, a qualitative, exploratory and inductive research method is used to investigate the impact of digital twin technology in increasing supply chain resilience and sustainability. The methodology is justified by the research purpose, which is to understand complex and real-world phenomena and not to test hypotheses previously set (Saunders et al., 2019).

3.2.1 QUALITATIVE APPROACH

A qualitative approach is employed to explore the experiences, perceptions, and insights of experts regarding digital twin technology. This approach is particularly suitable for studying complex and context-dependent phenomena such as supply chain resilience and sustainability, which cannot be fully captured through quantitative measures (Bryman and Bell, 2015).

By using qualitative data, the study enables a deeper understanding of how digital twin systems are applied in practice, particularly within large-scale logistics environments such as Amazon.

3.2.2 DESCRIPTIVE CHARACTER OF THE RESEARCH

The study will have a descriptive and exploratory orientation in order to give an in-depth explanation of the functioning of digital twin technology in the supply chains. The descriptive dimension enables the research to logically investigate the existing practices, and the exploratory character helps to reveal the new patterns and relations.

This is especially true, as the area of digital twins, resilience, and sustainability is still in the nascent phases of scholarly research.

3.2.3 INDUCTIVE REASONING

Inductive approach involves deriving insights of empirical data as opposed to testing existing theories (Saunders et al., 2019). The research examines expert interviews and secondary data to come up with major themes regarding digital twin application in the supply chain operations.

This method allows one to develop conceptual understanding of:

- How digital twins can be used to improve resilience (e.g., simulation and predictive modelling)
- How they contribute to sustainability (e.g., optimisation and reduction of emissions)
- What are the implementation challenges and opportunities.

3.2.4 RATIONALE FOR THE CHOSEN APPROACH

A qualitative, exploratory, and inductive method has been selected due to several reasons.

To begin with, the topic of the research is a new area of study in which theoretical advancements are minimal, and so the study is flexible and exploratory in character. Second, the multidimensionality of the global supply chain of Amazon requires a context-sensitive strategy that can accommodate variation in operations.

Moreover, qualitative methods are appropriate in the study because it will use the insights of experts working in the field and scholarly experts to produce the rich and interpretive information. Lastly, the methodology is in line with the pragmatism aspect of the study because it facilitates the formulation of practical recommendations to practice in the industry.

3.2.5 CONNECTION WITH RESEARCH QUESTIONS

The selected research method is well corresponding to the research questions since it will allow an in-depth discussion of digital twin’s applications in the interpretative perspective.

To show this congruency, Table 3.2 gives the correlation between the research questions and the reason why qualitative and exploratory approach should be adopted.

Research Question	Justification for Qualitative/Exploratory Approach
1. How does Amazon use digital twin technology to improve the resilience of its global supply chain?	Does not need quantitative numeric knowledge but interpretive knowledge of strategies, technologies, and experiences of experts.
2. In what ways do digital twins contribute to sustainability and carbon reduction in Amazon's logistics operations?	Includes investigating perceptions and illustrations of sustainable practices by use of narrative information.
3. What are the main challenges and opportunities in implementing digital twin systems in large-scale e-commerce logistics?	Insights that are explored assist in finding out the barriers, enablers and recommendations that arise out of the expert perspectives.

Table 3.2: Justification for approach to research questions
(Source: Developed by the authors (2026))

As it is demonstrated in Table 3.2, the research questions are interpreted in nature, not quantifiable. The qualitative method allows examining the professional knowledge, best practices and the practical use of digital twin technology in the supply chains.

Stage	Method	RQ1	RQ2	RQ3
Data Collection	Literature Review	•	•	•
	Case Study (Amazon)	•	•	
	Expert Interviews	•	•	•
Data Analysis	Thematic Analysis	•	•	•

Table 3.3: Alignment of Research Questions and Methodological Approaches
(Source: Developed by the authors (2026))

Table 3.3 also confirms this correspondence by indicating that the chosen methodological approach justifies the entire research design. All these tables prove that the selected research method is suitable to consider the aims of the study and guarantee the methodological consistency

3.3 RESEARCH DESIGN (CASE STUDY OF AMAZON)

Research design offers a systematic plan that directs data collection, data analysis, and interpretation to make sure that the objectives of the research are met in an orderly manner (Saunders et al., 2019). It creates the connection between the research philosophy, research approach and methods applied in the study.

The qualitative single-case study design is adopted since this is an exploratory and an interpretivist study that pays attention to the case organisation of Amazon. The given design will allow carrying out a profound and context-driven study of the role of digital twin technology in enhancing supply chain resilience and sustainability in an actual environment (Yin, 2018).

3.3.1 CASE STUDY STRATEGY AND JUSTIFICATION

A case study is referred to as an empirical study of a modern phenomenon during real life situation when the demarcations between the phenomenon and the context are not well outlines (Yin, 2018). The method is particularly suitable in answering how and why research questions that are the focus of the given study.

The strategy of a case study makes it possible to explore, in more detail, the digital twin implementation in an intricate organisational setting. It allows the incorporation of both technological, operational and strategic aspects and offers a comprehensive view which can never be obtained in the quantitative approach. Moreover, the case study design allows utilizing a variety of sources of data, which contributes to the increased depth and plausibility of the results (Saunders et al., 2019).

3.3.2 SELECTION OF AMAZON AS CASE COMPANY

Amazon is the case organisation of choice, as it leads the world in technological advancements and supply chain management. The company has actively adopted the use of high technologies, including artificial intelligence, Internet of Things (IoT), cloud computing, and simulators in

its logistics, which is why it turns out to be a highly relevant setting when it comes to the analysis of the implementation of the digital twin.

Moreover, the global supply chain at Amazon is marked by a high level of complexity and high volumes of operations as well as dynamic demand patterns. This will offer an excellent environment of examining the issue of resilience and sustainability under practical circumstances. The fact that the firm has a robust stake in its sustainability programs such as carbon reduction and operational efficiency also makes the organization a good fit in this study.

3.3.3 CASE STUDY DESIGN AND UNIT OF ANALYSIS

In this study, the case study design is single, embedded where the global supply chain of Amazon is the central unit of analysis. In this case, various dimensions are considered, such as the digital twin possibilities, the resilience of the supply chain, and sustainability results (Yin, 2018).

The enveloped design can be discussed as providing more in-depth and fine-grained comprehension of the functioning of digital twin technology with respect to various facets of supply chain management. This method will reinforce the study of the relationships between technological systems and operations processes, and this will lead to an all-inclusive assessment of the research problem.

3.3.4 DATA INTEGRATION AND CASE STUDY PROCEDURE

The case study has incorporated both the primary and secondary sources of data in order to come up with a thorough analysis. Semi-structured interviews with experts are used to gather primary data and secondary data comprise academic literature, industry reports, and company publications.

The study is conducted in a systematic process, where it starts with a literature review, then the collection of data, and thematic analysis. It is a systematic strategy that increases the accuracy of the study and causes it to be consistent with research goals (Saunders et al., 2019).

Moreover, the combined method of data sources also facilitates the triangulation of data, and thus contributes to the validity and credibility of the results since it allows cross-checking the information of various data sources (Yin, 2018).

3.3.5 ADVANTAGES AND LIMITATIONS OF CASE STUDY DESIGN

The case study design has several benefits, such as the possibility to suggest in-depth, context-oriented information on the complex phenomena. It enables the holistic insight into digital twin applications in real-life supply chain contexts and can be used to integrate various data streams.

Nevertheless, this is not the only method which also has disadvantages. The results were not as generalisable as they could be in other large-scale logistics organisations similar to the one studied, and the use of qualitative data could have brought subjectivity (Yin, 2018). Nevertheless, the case study design is suitable in this research, given that it is not that much interested in the generalisation, but rather the depth of understanding.

3.4 DATA COLLECTION METHODS

One of the most important processes in the research process is data collection as it offers the empirical basis on which one can answer the research questions and meet the objectives of the study (Saunders et al., 2019). The research will use qualitative data collection method in which both primary and secondary data will be used to have a thorough and well-supported analysis.

Figure 3.1 is given to offer a clear picture of the data collection process, which is the combination of primary and secondary data collection in this study.

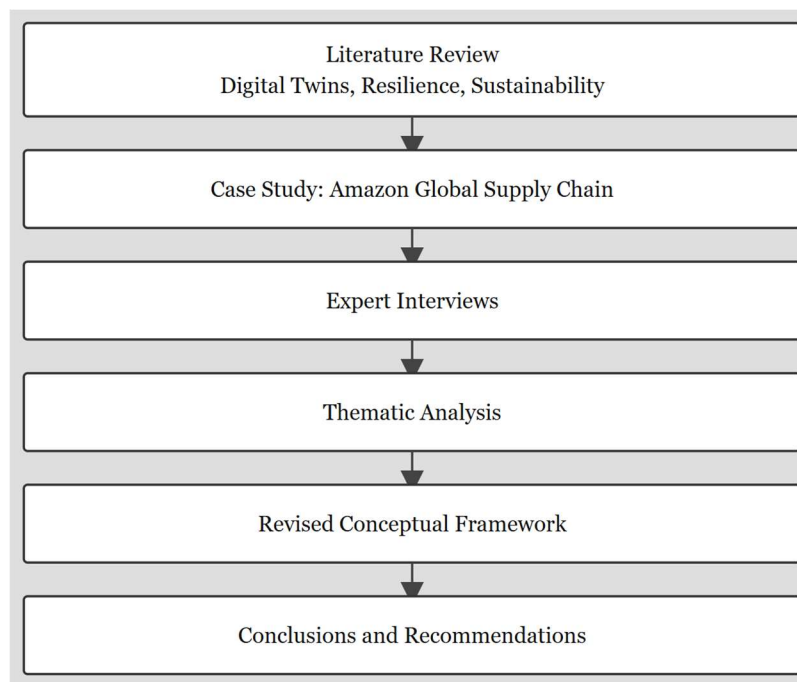


Figure 3.1: Research Methodology Framework
(Source: Developed by the authors (2026))

The research, as illustrated in Figure 3.1, combines both primary data which is collected by conducting expert interviews with secondary data collected by using academic literature, industry reports, and company publications. Such a combined method will help to triangulate the data, which increases the credibility and validity of the research results as it allows cross-checking the information obtained with several sources (Yin, 2018).

3.4.1 PRIMARY DATA COLLECTION: SEMI-STRUCTURED INTERVIEWS

The primary data were gathered with the help of semi-structured interviews with people who have the corresponding experience in the field of supply chain management and logistics, as well as in digital technologies. Semi-structured interviews were chosen because of their flexibility as the participants can give detailed information without compromising the objectives of the research (Bryman and Bell, 2015).

The interviews focused on:

- Application of digital twin in any type of supply chain.
- The contribution to their resilience and sustainability.
- Implementation issues and prospects.

The individual interviews were guided by a set interview guide, and a probing methodology to seek new themes.

The interviews were done over the phone and were recorded with the consent of the participants. To enhance efficiency, AI-assisted transcription tools were used to produce preliminary transcripts. These transcripts were then subjected to a manual review and revision to make them accurate and reliable.

3.4.2 SECONDARY DATA COLLECTION

Academic journal articles, industry reports, and company publications about the operations of Amazon supply chain were used as secondary data. These resources give background information and help to confirm the primary data results.

Secondary data makes the research stronger since it allows triangulation and helps to conduct a more in-depth analysis of the applications of digital twins (Yin, 2018).

3.4.3 JUSTIFICATION FOR DATA COLLECTION METHODS

The need to incorporate primary and secondary data collection techniques is explained by the complexity of the research issue. In the case of digital twin technology in supply chains, there should be theoretical and practical knowledge.

The semi-structured interviews give comprehensive expert views whereas the secondary data gives the wider contextual back-up. This combination method has improved reliability and validity of the study.

3.5 SAMPLING STRATEGY AND SELECTION OF INTERVIEWEES

Choosing relevant interview participants will be important in determining the credibility and relevance of the primary data. Since the proposed research seeks to uncover the views of experts on the use of digital twin technology to improve the resilience and sustainability of supply chains, purposive sampling approach is used.

Purposive sampling is a non-probability sampling method, where the respondents are chosen based on his/her expertise and interest in the subject under study (Saunders et al., 2019). The method is especially appropriate to qualitative and exploratory studies, in which the aim is to acquire deep, thick information as opposed to statistically generalisable findings.

3.5.1 SAMPLING STRATEGY

The purposive (judgemental) sampling is used in the study to select the persons who possess the knowledge of interests in the field of supply chain management, digital transformation, and sustainability. Along with this, snowball sampling is employed as a supplementary method and, in this case, the first participants would suggest other appropriate experts in their professional networks.

The hybrid strategy can improve the availability of expert knowledge, especially in new areas of digital twin's technology, where it might be difficult to find qualified specialists (Bryman and Bell, 2015).

The three major criteria used to select the participants include:

- **Relevance:** The participants need to have first-hand or second-hand experience in supply chain management, logistics, or digital technologies.

- **Experience:** A minimum of three years in professional or academic work in related areas.
- **Diversity of viewpoints:** Participants in industry and academia to make the viewpoint balanced.

3.5.2 TARGET PARTICIPANT CATEGORIES

To increase the level of transparency and methodological clarity, Table 3.4 contains the professional background of the participants of the interview who were incorporated in this study.

Interviewee	Position	Experience	Expertise Area
A	Senior Operations Manager	12+ years	Fulfilment & logistics
B	Analytics Specialist	8 years	Simulation & modelling
C	Academic/Industry Expert	10+ years	Resilience & sustainability

Table 3.4: Profile of Interview Participants
(Source: Developed by the authors (2026))

The respondents are a diverse group of professional knowledge as indicated in Table 3.4 between industry professionals and scholars. The diversity enhances the plausibility of the results since it involves the integration of diverse viewpoints on digital twin applications in the supply chain. It also facilitates data triangulation, which improves the strength of the thematic analysis (Yin, 2018).

3.5.3 SAMPLE SIZE

The qualitative research is more focused on the level of understanding rather than the size of the sample. Three semi-structured interviews were done in this research. This size is thought to be right, because the intention is to get detailed expert-led information as opposed to statistically generalising.

The sample size is justified in the concept of the data saturation which is the point at which a new theme or insight is not made by further data (Guest, Bunce, and Johnson, 2006). The sample is adequate to answer the research objectives considering the specialisation of the topic and knowledge of the people involved.

All interviews took about 30-45 minutes and were held online through such resources as Zoom or Microsoft Teams, which made them flexible and accessible to participants in various places.

3.5.4 RECRUITMENT PROCESS

Professional networking sites like LinkedIn, academic contacts and snowball samples were used to recruit participants under the snowball sampling method.

Potential participants were approached through official invitation mails which contained:

- A short description of the purpose of the research.
- Information about the interview format and time to take.
- Details on confidentiality, anonymity and voluntary participation.
- An information sheet and consent form signed by the participant that was recommended by the university ethics committee.

Those who consented to participate in the study affirmed their availability and made appointment interview sessions as well.

3.5.5 INCLUSION AND EXCLUSION CRITERIA

Inclusion and exclusion criteria were used to make sure that data is relevant and of quality.

Inclusion Criteria:

- At least three years of experience in supply chains management, logistics, digital transformation or sustainability.
- Direct or indirect engagement in digital technology/ supply chain operations.
- Voluntary Participation.

Exclusion Criteria:

- Less or no experience in the area of study.
- Failure to deliver knowledgeable information on digital twin applications.
- Inability or unwillingness to take part.

These are the criteria that will guarantee that the individuals that are selected are well-versed enough to bring significant and dependable information into the research.

3.6 DATA ANALYSIS TECHNIQUE (THEMATIC ANALYSIS)

Qualitative data analysis entails systematic organisation and interpretation of data to determine patterns, themes and relationships which are pertinent to the research objectives (Braun and Clarke, 2006). Contrary to quantitative methods, it aims at the depiction of the richness and the complexity of experiences and viewpoints of the participants.

Since this research is exploratory and interpretivist in nature, thematic analysis is embraced as the major technique of analysis. Thematic analysis is a versatile and stringent method of detecting, interpreting and recording tendencies in qualitative data (Nowell et al., 2017). It is also well-suited to this study, because it allows to combine the data offered by the expert interviews with the results found in the secondary sources of information.

To demonstrate the process of analysis, Figure 3.2 outlines the coding scheme that will convert unstructured information gotten in the interviews to structured themes.

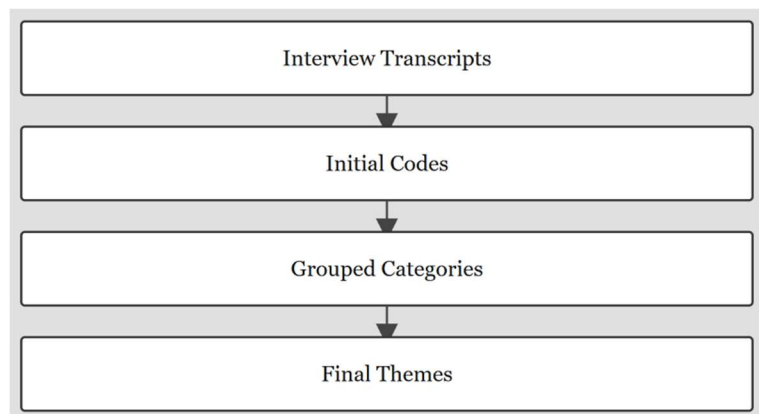


Figure 3.2: Interview Coding Framework
(Source: Developed by the authors (2026))

As it is presented in Figure 3.2, the data of the analysis is initially raw interview data, which is coded and sorted into meaningful categories in a systematic way. These codes are further categorised into more broad themes that represent major patterns in terms of digital twin application, supply chain resilience, and sustainability. This is done in a systematic manner, so that there are uniformity and clarity in the analysis process.

3.6.1 RATIONALE FOR CHOOSING THEMATIC ANALYSIS

Thematic analysis has been chosen because of its flexibility and its appropriateness in exploratory research. It enables the researcher to analyse both overt and subtextual messages conveyed by the data, which gives a better insight into the views of the participants.

Moreover, thematic analysis facilitates the incorporation of various data sources, thus triangulating interview data and secondary data in the form of reports and academic publications. The six-phase process that is proposed by Braun and Clarke (2006) provides the analytical rigor and transparency of the study.

3.6.2 THEMATIC ANALYSIS PROCESS

The review is based on the six-step model proposed by Braun and Clarke (2006), which guarantees a methodological and thorough analysis.

Phase 1: Data Familiarisation

Interview tape recordings were transcribed and read repeatedly to familiarize oneself with the information. At this point, initial impressions, main concepts and possible patterns were recorded.

Phase 2: Initial Coding

Appropriate parts of the data were coded systematically to record significant ideas of the research aims. Inductive coding (emerging out of the data) and deductive coding (out of the existing literatures) were used, and this gave a hybrid method of analysis (Fereday and Muir-Coachrane, 2006).

Phase 3: Theme Development

The codes were placed into larger themes that embodied major trends in the data. These are resilience based on predictive capabilities, sustainability optimisation, and implementation issues.

Phase 4: Theme Review

Reviewing and refining of themes to facilitate coherence, consistency, and alignment with the research questions were done. Duplicate or insignificant themes would be combined or cut.

Phase 5: Themes Defining and Naming

All the themes were well explained with regard to meaning, scope and relevancy to the study. Interpretations were strengthened with the help of support evidence on the one hand, both interviews and secondary information.

Phase 6: Reporting and Interpretation

The last phase was the synthesis of findings into a logical narrative that can directly answer the research questions and connect empirical knowledge with a theoretical understanding.

3.6.3 INTEGRATION OF SECONDARY DATA

The secondary data sources, such as the scholarly writings and the industry reports were incorporated into the analysis with the aim of backing and confirming the results obtained through the interviews. This methodology makes the analysis stronger as it allows comparing the results of several sources and reinforces the entire interpretation (Yin, 2018)..

3.6.4 ENSURING ANALYTICAL RIGOR

To ascertain the credibility and reliability of the analysis, several measures were embraced. To begin with, the structured coding process increases the transparency and consistency. Second, primary and secondary data triangulation enhances sound findings.

Moreover, even though the initial interview transcripts were generated with the help of AI-assisted tools, all of them were checked and verified by reviewing and, finally, coded. This will provide accuracy and integrity of the analysis.

3.7 VALIDITY, RELIABILITY, AND TRIANGULATION

To bring the reliability of the qualitative research, its trustworthiness is necessary to improve the credibility and rigor of the research. Credibility, dependability and triangulation are the concepts typically applied in the qualitative research, replacing the conventional validity and reliability measures (Lincoln and Guba, 1985).

In this study the researcher employs various strategies to make sure that the results of this research are robust, consistent, and they are in the context of the research objectives.

3.7.1 VALIDITY (CREDIBILITY)

Credibility is a level of validity of the results and whether they are a true reflection of the point of view of the participants and the reality under study (Lincoln and Guba, 1985). Credibility is upheld in this study in several ways.

In the first place, the method of semi-structured interviews enables the participants to give more detailed and context-based information. Second, triangulation of data is used through the comparison of the results of interviews with the secondary sources of data like scholarly literature and industry reports.

Also, the researcher involved herself in many repetitive readings of the transcripts of the interviews to maintain a true interpretation of answers. This is done to reduce misinterpretation and contributes to the overall credibility of the findings.

3.7.2 RELIABILITY (DEPENDABILITY)

Dependability is the constant consistency and stability of the research process over an extended period (Saunders et al., 2019). In order to provide reliability, this research paper is presented based on a clear and systematic research process, which involves structured data collection and a clear procedure of thematic analysis.

Reliability is also improved by the fact that a time-tested analytical framework was used (Braun and Clarke, 2006) and this approach was used in coding and developing a thematic analysis.

In addition, all interview transcripts, including those that were originally produced with the help of AI tools, were checked and checked by hand. This also guarantees accuracy and consistency of data used to analyse.

3.7.3 TRIANGULATION AND OVERALL TRUSTWORTHINESS

Triangulation is the concept of validation of research findings with the help of several data sources, methods, or perspectives (Yin, 2018). Triangulation is fulfilled in this research through integration:

- Primary data since it includes interviewing with specialists.
- Secondary information in scholarly literature, reports and company documents.

The multi-source methodology will allow the cross-verification of the results and increase the general strength of the analysis.

In short, the strategies implemented to guarantee the quality of the research are summarised in Table 3.5 which displays the major trustworthiness criteria and the respective measures implemented in the present study.

Criterion	Equivalent in Quantitative Research	How It's Achieved in This Study
Credibility	Internal Validity	Triangulation of data, member verification, rich description.
Transferability	External Validity / Generalizability	Extensive contextualization to enable the reader to give a verdict on applicability to other organizations.
Dependability	Reliability	Clear audit trail, codebook, regular and standardized data processing.
Confirmability	Objectivity	Reflexive journalizing, managerial audit, decision journaling.

Table 3.5 Framework based on four dimensions
(Source: Developed by the authors (2026))

The study, as revealed in Table 3.5, employs various strategies to guarantee credibility, dependability, and confirmability. All these actions contribute to the increased credibility of the study and make the results both rigorous and substantiated.

3.8 ETHICAL CONSIDERATIONS

Ethical considerations play vital roles in responsible conduction of research without infringing the right, privacy and well-being of the participants. In this study, the researcher will follow the recommended codes of ethics in conducting research to ensure integrity and safeguard the interests of all research participants (Saunders et al., 2019).

3.8.1 INFORMED CONSENT

All the participants provided informed consent before data collection. The participants were also given detailed information on why and how they were used and their right to pull out any time without a penalty.

The consent was taken based on signed consent forms and so the participation was voluntary based on clear realization of the research process.

3.8.2 CONFIDENTIALITY AND ANONYMITY

All answers to questions were provided with high confidentiality to ensure the identity of the participants was safeguarded. Transcripts were anonymised and participants were given anonymised labels (e.g. Interviewee A, B, and C).

This will guarantee the ability not to point to individual participants in the final result of the research and preserve their privacy and integrity.

3.8.3 DATA PROTECTION AND STORAGE

Any information taken during research was safely kept in the digital systems that had passwords. The researchers were the only ones allowed to access the data.

Recording and transcripts of the interviews, even the ones originally created with the help of AI tools, were stored in a safe place and were utilized in academic work only. Data shall be stored to the extent that the university directs and then securely destroyed.

3.8.4 ETHICAL COMPLIANCE

The research is in line with institutional ethical standards and guidelines. The research design was approved ethically before data collection to make sure that the research design satisfied all the necessary requirements.

In addition, the research offers transparency, honesty, and accuracy in data collection, data analysis, and reporting, thus, upholding the overall integrity of the research process.

3.9 LIMITATIONS OF THE RESEARCH METHODOLOGY

Despite the strengths of the selected research design, it is worth noting the limitations that relate to the approach. Determining such limitations improves the impartiality and integrity of the research and gives background to the understanding of results (Saunders et al., 2019).

3.9.1 METHODOLOGICAL LIMITATIONS

The research is based on a qualitative and interpretivist approach and case study that gives more value to depth of understanding than generalisability. Although this method allows one to gain deep and context-specific knowledge regarding digital twin applications, it can preclude the possibility to make generalised conclusions about various organisations or industries.

In addition, qualitative research is interpretive in nature implying that the findings are subject to the opinion of the researcher. Systematic procedures were used to bring some consistency, but some subjectivity cannot be completely eradicated.

3.9.2 DATA COLLECTION LIMITATIONS

The limited number of expert interviews was used to collect primary data. Although the respondents gave insightful and comprehensive information, the sample size can be considered a limitation since it might not be diverse enough on the perspective that can be represented in the study.

Moreover, interviews are dependent on the knowledge and experiences of participants that can present biasness and incomplete information. The fact that the use of AI-assisted transcription is making the process more efficient does not mean that the process will be without errors, but this was corrected by the manual verification of transcripts.

3.9.3 GENERALISABILITY AND SCOPE

The specificity of one case organisation Amazon gives a rich insight into the application of digital twins in a context-dependent manner but restricts the extrapolation of the results to other organisations or sectors.

Besides, the present research focuses on the supply chain resilience and sustainability without considering other possible dimensions that might include financial performance or customer satisfaction. Though such a narrow area of coverage enables a detailed analysis, it can hamper the external scope of the findings.

CHAPTER 4: FINDINGS AND ANALYSIS

4.1 OVERVIEW OF AMAZON'S GLOBAL SUPPLY CHAIN

Amazon has one of the most complicated and sophisticated chain supply systems globally in the current e-commerce environment. It has got a logistics network that is made up of fulfilment centres, sortation hubs, regional distribution centres, air and land transport fleet and last mile delivery systems which are integrated by use of sophisticated digital infrastructure (Christopher, 2016). This system is large and massive in scale and scope, thus allowing Amazon to control a large geographical distribution of inventory besides coordinating millions of real-time operational decisions as customer demand rises and falls (Mollenkopf et al., 2010).

This supply chain arrangement and complexity can be explained by the fact that it is based on an information-driven operational model, in which efficiency and responsiveness are the results of constant information flow and integration of systems. The inventory is the advantageous distribution of the inventory between various fulfilment centres in order to reduce the lead time and provide quick delivery solutions like same-day and next-day delivery (Hubner, Kuhn & Wollenburg, 2016). In addition, the sophisticated automation systems such as robotics, conveyor and automated sortation processes are combined with human labour in order to streamline throughput and resource exploitation. Digital planning systems which predict demand, allocate inventory optimally and make workforce requirements dynamically assist in these capabilities (Ivanov, Tsipoulaidis & Schonsleben, 2019).

One of the distinguishing features of the Amazon supply chain is the real-time information architecture, in which the operational data are constantly monitored with the help of sensors, warehouse management systems, and transportation tracking platforms. This makes the visibility of the entire logistics network more visible and allows making fast and data-driven decisions in real-time (Waller and Fawcett, 2013). This kind of responsiveness resonates with the current supply chain paradigms which focus on agility, flexibility, and resilience (Saghafian and Van Oyen, 2019).

Nonetheless, the complexity and interconnectivity that leads to efficiency also creates vulnerabilities on the system level. One network failure can spread quickly throughout the

entire system unless handled efficiently (Ivanov & Dolgui, 2020). Such risks underscore the growing relevance of sophisticated digital tools that are able to perform predictive analysis and adaptive response especially in the management of uncertainty caused by variation in demand, capacity, and external disturbances like season peaks or world wars.

To present the empirical results of the interviews with experts in a structured way, Figure 4.1 will include the thematic structure, on which the analysis is based.

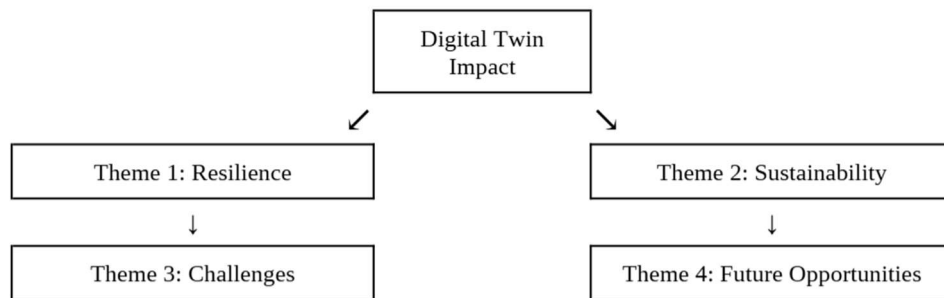


Figure 4.1: Thematic Structure of Findings
 (Source: Developed by the authors (2026))

They are systematically grouped into major thematic areas of concern, as indicated in Figure 4.1 that capture the key dimensions of resilience in the supply chain, sustainability, challenges in implementation and potential strategic opportunity in the future. It is a thematic structure that will serve as the backbone of the further analysis in the current chapter.

Moreover, Figure 4.2 conceptualises the integration of a digital twin technology into the supply chain of Amazon.

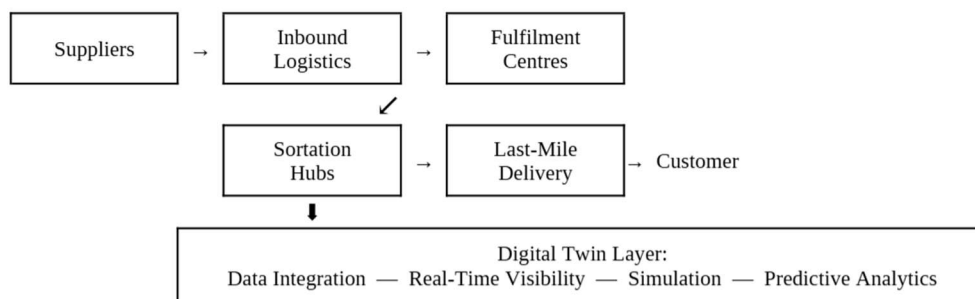


Figure 4.2: Architecture of Amazon’s Global Supply Chain with Digital Twin Integration
 (Source: Adapted by the authors from Amazon (2023) and related literature)

Figure 4.2 illustrates the way in which digital twin technology superimposes the physical logistics network, allowing real-time monitoring, predictive modelling and scenario simulation. Digital twins enable improved decision-making, risk management, and resource distribution optimization through developing a virtual representation of physical operations. Such integration indicates the increased influence of digital technologies on the enhancement of the resilience and sustainability performance of supply chains (Ivanov & Dolgui, 2020).

4.2 EVIDENCE OF DIGITAL TWIN APPLICATIONS AT AMAZON'S SUPPLY CHAIN

Digital twin technology (when applied to the supply chain management) has been a popular topic in the past few years especially in large and data-intensive settings, like with the Amazon logistics network. One possible definition of a digital twin is a virtual model of a real-life system constantly being updated with real-time data, which allows simulation, monitoring, and predictive analysis (Tao et al., 2019). When applied to the Amazon business, it is not always mentioned that they have a digital twin, but a number of technological functions performed closely resemble those of a digital twin.

The supply chain of Amazon has features that align with the digital twin architecture with its incorporation of real-time data systems, predictive analytics, and simulation-based decision-making systems. These features enable the organisation to see the activities in fulfilment centres, transportation, and last-mile delivery networks in real time and, as a consequence, improve visibility and operational control (Waller and Fawcett, 2013).

Inventory and demand forecasting is one of the examples of where the digital twin capabilities can be observed. Amazon employs machine learning models to forecast demand and proactively distribute inventory in its network. This allows developing virtual models of inventory flows that enable the enterprise to run a variety of demand scenarios and optimise the position of the stock, respectively (Ivanov et al., 2019). These abilities are correlated with the concept of digital twins wherein the virtual models are employed to test and optimise the performance of the system before deployment in the physical world.

The other significant use is warehouse operations and fulfilment centres. Amazon uses robotics, automation systems, and sensor-based tracking technologies to ensure the control and monitoring of activities in the warehouse. Such systems produce ongoing flows of operation data, which can be employed to form digital images of the management of the warehouse.

Through simulation and optimisation, Amazon will be able to streamline picking, lower processing time and overall throughput (Boysen, de Koster & Weidinger, 2019).

Moreover, transportation and route optimisation is another important field where digital twins are implemented. The logistics system of Amazon includes real-time monitoring of vehicles and shipments, which allows planning and variation of routes depending on traffic parameters, delivery limitations and variability of demand. The supporting systems promote the use of scenario analysis and predictive decision-making, which are essential elements of digital twin capabilities (Ivanov and Dolgui, 2020).

Also, the digital twin opportunities are used in risk management and resilience planning. It will be possible to test other options and react better to unforeseen circumstances by simulating possible perturbations, including demand surges, transport slowdowns, or capacity limits, as Amazon can consider different approaches. This is in line with the definition of supply chain resilience, according to which organisations use digital capabilities to forecast, prepare, and recover disasters (Christopher and Peck, 2004).

Operational efficiency and resource optimisation are also sustained through digital twin technologies in terms of sustainability. With the help of analyzing the data on energy use, transportation paths, and warehouse functioning, Amazon will be able to find an opportunity to use less fuel, lessen emissions, and enhance the overall environmental results. These features reveal the way digital twins may not only be helpful to efficiency, but also to larger sustainability goals (Tao et al., 2019).

Overall, the evidence indicates that the supply chain of Amazon implements various aspects of digital twin technology, although it may not be denoted as such. Real-time data, predictive analytics, and simulation-based decision-making integration allows achieving improved visibility, operational efficacy, and resiliency. It is based on these capabilities that the thematic analysis is developed on in subsequent sections where responses given by experts are analysed further.

4.3 FINDINGS FROM EXPERT INTERVIEWS

The following section summarizes the most important findings of the interviews with the industry and academic experts held within the frame of the semi-structured interviews. The discussion reveals that there are several similar themes regarding the role of digital twin in the

improvement of supply chain resilience, aiding sustainability, and the obstacles to its application.

4.3.1 DIGITAL TWIN CAPABILITIES AND OPERATIONAL VISIBILITY

Another commonality in all interviews is the application of digital twin-like systems in improving real-time visibility in the Amazon supply chain. Respondents noted that even though the concept of a digital twin is not always directly applied practically, many operationalized systems operate in such a way that they offer live images of the physical processes.

A respondent has pointed out that models of the type of digital twins allow incorporating several factors of operation, such as inventory quantity, throughput, labour supply, and transport limitations, into a single system to monitor and make decisions (Interview A) . On the same note, Interview B reflected the digital twins as a decision layer, which combines data of multiple sources and allows analysis by scenarios (Interview B).

The results however also tell that an elevated visibility does not necessarily result in better decision-making. According to Interview C, organisational forces like governance and alignment are paramount in interpreting the data insights into actions (Interview C) that are effective. This indicates that digital twin's potential should be backed up by powerful organisational processes to enable its effective implementation.

4.3.2 ROLE OF DIGITAL TWINS IN SUPPLY CHAIN RESILIENCE

The relevant participants concurred that digital twin technologies play a vital role in resilience of the supply chain especially when it comes to simulation of scenarios and predictive modelling. These abilities enable organisations to foresee the possible disruptions and analyse the other approaches prior to execution.

As an example, Interview A emphasized the utilization of simulations to train during the peak demand times and make changes in staffing and operational settings to enhance efficiency and eliminate bottlenecks. On the same note, Interview B highlighted the stress-tests of supply chain networks through digital twins in the extreme conditions, e.g., congestion or supplier failures.

Although there are these benefits, there are significant limitations that the findings indicate. The participants observed that digital twins are not totally predictive of disruptions and rely on

the quality of data and model accuracy. This leads to increased but not certain resilience, which supports the importance of human judgement and adaptable decision-making.

4.3.3 CONTRIBUTION TO SUSTAINABILITY AND OPERATIONAL EFFICIENCY

According to the interviews, digital twin's technologies seem to contribute to sustainability by means of incremental efficiencies and not a radical change. Respondents pointed out various sections in which digital twins can be used to enhance environmental performance such as transportation routes optimisation, minimisation of unnecessary inventory flows, and better resource utilisation.

Interview A observed that through digital twins, inefficiencies in the packaging and inventory management can be minimized and that will result in the reduction of resource consumption. Interview B also emphasized the capability to assess the environmental effects as well as the costs and service measures, which allow making a more informed decision.

An important learning though is that there are trade-offs between sustainability and operational priorities that are observed across the interviews. Indicatively, Interview B indicated that sustainability goals tend to be conflicting with speed and cost features and Interview C indicated that sustainability knowledge needs to be incorporated in the decision-making in a way that it renders a significant contribution to the decision-making process.

4.3.4 CHALLENGES AND LIMITATIONS OF DIGITAL TWIN IMPLEMENTATION

A few issues related to the implementation of the digital twin were found throughout the interviews. Data integration and quality is the most outstanding problem, and it has a direct impact on the quality and reliability of digital twin's models.

Interview A emphasized the fact that incomplete or inconsistent data minimizes the usefulness of digital twin's systems, whereas Interview B emphasized the fact that complex models are expensive to maintain at scale. Furthermore, Interview C highlighted the expensive and intricate nature of the organisational structure in executing digital twins technologies on a large scale.

The other critical threat is the threat of dependence on models. Participants noted that digital twins must be seen as decision-support systems and not independent solutions because they could not necessarily reflect the real-world uncertainties and behavioural aspects.

4.3.5 FUTURE OUTLOOK AND STRATEGIC IMPLICATIONS

In prospects, the members anticipate the digital twin technologies to evolve to a higher level, especially when it comes to automation, prediction, and system integration. Nonetheless, it is almost unanimously agreed that these technologies will only act as an addition, as opposed to a substitution of human decision making.

Interview A and Interview B both emphasised the growing significance of predictive analytics and adaptive systems, whereas the Interview C focused on the necessity to preserve transparency and knowledge the limitations of a model.

In general, the results indicate that the future of digital twins is in their capability to improve the level of decision making and being incorporated in the overall organisational and strategic processes.

4.4 DISCUSSION AND THEMATIC ANALYSIS

This part critically evaluates the results contained in Section 4.3 in terms of their affiliation to the theoretical ideas outlined in Chapter 2. The aim is to test the alignment, expansion, or subversion of the available literature on the digital twin technology, supply chain resilience, and sustainability by the empirical evidence.

To offer an organized account of the thematic linkages which have been found in this research, Table 4.1 suggests the correspondence of what the interviews found to be important in the research and the major themes, and the theoretical ideas which are pertinent.

Theme	Description	Supporting Interviewees
Resilience	Scenario modelling & visibility	A, B, C
Sustainability	Carbon tracking & efficiency	A, B, C
Barriers	Data complexity & integration	A, B, C
Future Role	Predictive automation	A, B, C

Table 4.1: Summary of Emergent Themes from Expert Interviews
(Source: Developed by the authors (2026))

The constructive results of the empirical investigation are aligned with major theoretical constructs, especially regarding the capabilities of digital twins, resilience mechanisms, and sustainability outcomes as revealed in Table 4.1. Nevertheless, the results also demonstrate several practical limitations and trade-offs that are not highlighted in the extant literature

4.4.1 THEME 1: DIGITAL TWIN CAPABILITIES AND SUPPLY CHAIN VISIBILITY

The results reveal that digital twin technologies are important in improving real-time visibility and decision-making in supply chains. This is consistent with the available literature, which emphasizes the role of data integration and transparency across the system in enhancing the performance of the operations (Waller and Fawcett, 2013; Ivanov et al., 2019).

According to the participants of the interview, digital twin systems have been characterized as a platform that consolidates information collected by various sources and gives a full picture of the activity of a supply chain. These observations are aligned with how digital twins have been conceptualised as dynamic and data-based models of physical systems (Tao et al., 2019).

Nevertheless, the results enlarge the literature by illustrating that visibility does not necessarily result in a better decision. Organisational aspects, including governance, data quality, and alignment are some of the key factors that affect the effectiveness of digital twins as noted by participants. This implies that technological capability is not enough and needs proper organisational structures.

4.4.2 THEME 2: DIGITAL TWINS AND SUPPLY CHAIN RESILIENCE

The findings have a robust position in favour of the digital twins to increase the resilience of supply chains, especially simulation and predictive modelling. This is aligned with the previous studies, which highlight the capability of digital technologies to enable proactive risk management and mitigation of disruptions (Ivanov & Dolgui, 2020).

As noted in the interview, scenarios of digital twins include scenario planning through which supply chain networks are stressed-tested and demand fluctuations planned. Such capabilities are in line with the resilience concept of anticipating, responding, and recovering disruption (Christopher and Peck, 2004).

Nonetheless, significant limitations are also discovered in the findings. The participants underlined that digital twins are not able to predict all disruptions completely but rely on the accuracy of data and assumptions of the models. This disputes the idea that digital technologies

can offer total control over supply chain uncertainty. Rather, the results indicate that supporting digital tools with human judgment allows creating resilience.

4.4.3 THEME 3: SUSTAINABILITY AND OPERATIONAL TRADE-OFFS

The results show that digital twin technologies have a positive impact on sustainability in the form of efficiency (optimisation of transportation routes), minimisation of wastage of unnecessary resources. This contributes to the current research associating digital twins with a better environmental performance (Tao et al., 2019).

Nevertheless, one major observation that comes out of the analysis is that there exist trade-offs in the areas of sustainability, cost, and service performance. Respondents added that sustainability goals are usually second gear to operational considerations especially in high-paced e-commerce settings.

This discovery provides a valuable contribution to the literature as it shows that, although digital twins can allow analysing sustainability, they are not necessarily based on the environmental outcomes. Rather, the effect of digital twins on sustainability resides in the ability of the organisations to balance contradicting goals in their decision-making steps.

4.4.4 THEME 4: IMPLEMENTATION CHALLENGES AND ORGANISATIONAL BARRIERS

In line with the current literature, the results found that data integration, system complexity, and scalability are significant issues in implementing the digital twins (Ivanov and Dolgui, 2020).

The participants emphasized that the lack of completeness or accuracy of data makes digital twins less efficient, whereas the complexity of scale demands a substantial amount of resources. The insights add weight to the significance of data governance and system integration in effective digital twin implementation.

Also, the results indicate the danger of excessive dependence on digital models, which is less common in the literature. This implies that organisations should strike a balance between evidence-based findings and the human skills to prevent failure to understand and excessively trust model results.

4.4.5 SYNTHESIS OF THEMES

In general, the results show that digital twin technology can strengthen the resilience of the supply chain and help the organisation achieve its sustainability goals, yet the success of this technology depends on organisational, technological and strategic aspects.

It is noted that in the analysis, digital twins are perceived as decision-support systems, but not entirely autonomous solutions, as they must be combined with human judgement and organisational processes. This view builds up the current literature as it highlights the socio-technical character of the digital twin application in the environment of a complex supply chain.

4.5 CROSS-ANALYSIS WITH LITERATURE

In this section, the empirical data obtained after interviewing experts are combined with the available literature so that their findings could be viewed as helping to support, extend or disprove the existing theoretical views on the use of digital twin technology in supply chain management. The analysis follows the four main themes that were identified in Section 4.4 and correlated with the research questions.

4.5.1 CORRELATION WITH LITERATURE ON SUPPLY CHAIN RESILIENCE

The results are in line with the current literature that emphasizes that digital twin technology can be used to increase supply chain resilience due to real-time visibility and predictive modelling (Ivanov & Dolgui, 2020).

In line with Christopher and Peck (2004), resilience can be defined through being able to foresee, react to and recuperate the disruption. The results of the interview confirm that digital twins make it possible through the provision of scenario simulation and proactive decision-making.

Nevertheless, the results further widen the literature by showing that technological capability is not the only factor that increases resilience. The participants highlighted the significance of the organisational conditions, including governance and decision-making framework, in converting the digital insights into productive action. This has the implication that resilience is socio-technical, and not a technological consequence.

4.5.2 DIGITAL TWINS AND SUSTAINABILITY IN RELATION TO EXISTING RESEARCH

Its results are consistent with the available literature where digital twins are viewed as facilitators to sustainability by optimising resources and efficiency (Tao et al., 2019; Waller and Fawcett, 2022).

The participants of the interviews emphasized that digital twins will help to minimize inefficiencies in transportation and inventory management, which confirms previous research that digital technologies can lead to the enhancement of the environmental performance.

Nevertheless, the results also disprove the belief that digital twins necessarily result into an increase in sustainability. The availability of trade-offs between cost, speed, and environmental goals implies that the sustainability outcomes depend on the priorities of the organisations. This expands the literature by highlighting the fact that the digital twin technologies offer the ability to be sustainable, but not to be implemented.

4.5.3 IMPLEMENTATION CHALLENGES AND SOCIOTECHNICAL PERSPECTIVES

The results align with the literature on the topic that has singled out data integration, system complexity, and scalability as key obstacles to the implementation of digital twins (Ivanov and Dolgui, 2020; Fuller et al., 2020).

Nonetheless, the empirical evidence offers some further information by establishing the significance of human and organisational variables, such as knowledge and skills, decision-making procedures, and change resistance. These results help to believe that the implementation of digital twins should be employed in the context of a sociotechnical system.

Moreover, the results pose the problem of excessive dependence on digital models, which is not highlighted in the literature. This implies that organisations should ensure that they strike a balance between relying on technology and using critical human judgment in order to make effective decisions.

4.5.4 STRATEGIC IMPLICATIONS AND DYNAMIC CAPABILITIES

Strategically, the results are consistent with the Dynamic Capabilities Framework that focuses on how an organisation can sense, seize and reconfigure resources when there is a change in the environment (Teece, 2007).

Digital twin technologies assist in these functions since they allow real-time monitoring (sensing), data-informed decisions (seizing), and adaptive operational responses (reconfiguring). This supports the point that digital twins are strategic facilitators of organisational agility and resilience.

The results, however, also indicate that these capabilities require a major investment in the infrastructure, data system, and organisational alignment to evolve. This underscores the need to incorporate digital twin efforts in the larger strategic contexts.

4.5.5 SYNTHESIS OF EMPIRICAL AND THEORETICAL INSIGHTS

All in all, the cross-analysis shows that the evidence mostly confirms the theoretical approaches to the digital twin technology, especially concerning resilience and operational efficiency.

Concurrently, the research has contributed to the literature in creating awareness of the significance of the organisational and strategic factors in identifying the effectiveness of digital twin systems. The implications of the results are that digital twins ought to be designed as decision-support systems integrated into socio-technical systems, and not as technological systems.

This combined view can give a more holistic vision of the ways in which digital twins can bring greater resilience and sustainability to supply chains in the real and complex worlds like the global logistics network of Amazon.

4.6 SUMMARY OF KEY INSIGHTS

This chapter provided the empirical data of the research, the role of the digital twin technology in the supply chain of Amazon, and its implications to resiliency, sustainability, and implementation.

The review showed that the digital twins will significantly improve the supply chain resilience due to the possibility to provide real-time visibility, predictive modelling, and scenario planning. These abilities enable organisations to get ahead and react to disruptions better but their efficiency relies on the quality of information and combining human decision-making.

Regarding sustainability, the results show that digital twins result in better operational efficiency and resource optimisation. The results of sustainability however are not a given and tend to be affected by trade-off between the environmental goals and cost and service delivery.

This brings out the relevance of organisational priorities on determining sustainability outcomes.

Some of the implementation challenges that were identified in the study are the problem of data integration, complexity of system and the problem of scalability. Furthermore, organisational conditions like knowledge and skills, and change resistance were identified as a factor that has a critical influence on the success of the digital twin adoption.

Lastly, the results highlight the strategic nature of digital twins as decision-support systems that can be used to achieve more responsive and information-driven supply chain management. As opposed to being fully autonomous technologies, digital twins exist in a wider socio-technical environment which demands alignment of technology, processes and human abilities.

In general, the most important lesson that can be learned after reading this chapter is that digital twin technology has the potential to improve both resilience and sustainability, although its efficiency depends on organisational, technological, and strategic integration.

The following chapter will be based on these findings, where the results will be given in terms of the research questions and the current theoretical frameworks.

CHAPTER 5: DISCUSSION

5.1 INTERPRETATION OF FINDINGS IN RELATION TO RESEARCH QUESTIONS

This chapter will explain the empirical results of Chapter 4 in the direct manner of answering the research questions of this study. The analysis will combine the findings of the expert interviews and secondary sources with the theoretical premises in Chapter 2, specifically in the case of digital twin technology, supply chain resilience, and sustainability.

5.1.1 INTERPRETATION IN RELATION TO RQ1: DIGITAL TWINS AND SUPPLY CHAIN RESILIENCE

The results indicate that the digital twin technology can profoundly increase the supply chain resilience due to the increased visibility, predictive, and real-time decision-making. The experience in the Amazon case shows that the concept of digital twins allows constant monitoring of logistic processes and simulating situations, which allows organizations to foresee disruptions and react in advance.

This is in line with the existing body of literature that digital twins can improve resilience by high sensing, responding, and recovery (Ivanov and Dolgui, 2020; Tao et al., 2019). This understanding is elaborated by the empirical findings, which show how these capabilities are operationalized in a large scale, and highly complex supply chain like that of Amazon. More specifically, predictive analytics combined with real-time data allows making decisions much quicker and more informed, which is highly essential in addressing uncertainty and disruptions.

Additionally, the results suggest that digital twins can help in proactive and reactive resilience (simulation and forecasting and rapid response and adaptation) and strengthen the fact that supply chain resilience is a multidimensional concept as it has been mentioned in the previous studies (Christopher and Peck, 2004). This implies that digital twin can be viewed as a strategic enabler of resilience capabilities besides it being a monitoring tool.

5.1.2 INTERPRETATION IN RELATION TO RQ2: DIGITAL TWINS AND SUSTAINABILITY OUTCOMES

Another aspect that can be identified in the findings is that digital twins contribute to the goals of sustainability, especially the minimization of CO₂ emissions and resource efficiency. The case with Amazon shows that, with the help of digital twins, the transportation routes, the work of a warehouse, and inventory management can be optimized and, as a result, the positive environmental effect will be measurable.

These results can be compared with the previous literature that highlights the potential of digital technologies to improve sustainability performance by means of data-driven optimization (Kamble et al., 2020; Geissdoerfer et al., 2017). Nonetheless, this research goes a step further to illustrate that the concept of digital twin applications in particular can bring about sustainability at an operational level in supply chains.

Notably, the results indicate that the idea of sustainability does not become an inevitable effect of the implementation of digital twins but the effect of the strategic implementation of the technology and its integration into the workflow. This helps in making a case that the digital transformation should be synchronized with organizational sustainability to create meaningful environmental effects.

Also, the analysis shows that the resilience and sustainability are closely interrelated so that the enhancement of the performance in terms of operational efficiency and risk management also leads to the improvement of the environmental performance. This supports the newfound view that resilience and sustainability are not conflicting goals in the management of supply chains, but complementary.

5.1.3 INTERPRETATION IN RELATION TO RQ3: CHALLENGES AND IMPLEMENTATION BARRIERS

Along with the abovementioned great benefits, certain challenges linked to the introduction of the digital twin technology can be also found. They are high implementation costs, complexities of integrating data, technological infrastructure requirements, and resistance to change by the organization.

The barriers fit in with the sociotechnical perspective that has been identified in literature and this is the influence of technological systems, human, organizational, and cultural factors

(Bostrom and Heinen, 1977). The findings expand this viewpoint as they demonstrate that the effective adoption of digital twins needs not only high-level technological advantages but also organizational orientation, multi-functional teamwork, and change management.

Furthermore, the paper finds data quality and interoperability to be the most important issues, especially in a large-scale supply chain where systems and stakeholders interact with a considerable number of parties. This is consistent with current studies into the issue of digital transformation in supply chains (Ivanov et al., 2021), but more importantly, it indicates the complexity of application in real-life situations.

These results also indicate that the advantages of digital twins will be dependent on how well the organization can handle these issues. This highlights the need to take a holistic approach to implementation that would consider both technical and organizational levels.

5.1.4 OVERALL INTERPRETATION AND SYNTHESIS

Overall, the results show that digital twin technology is a strategic tool to achieve not only resilience and sustainability of the supply chain but also bring new complexities to implementation. The findings affirm and go beyond the theoretical viewpoints, by showing how digital twins can support solutions to dynamic capability like sensing, seizing, and reconfiguring to supply chain environments (Teece, 2007).

Simultaneously, the research points out that such benefits can be successfully realized when the technological, organization, and strategic factors are well integrated. This supports the argument that a holistic digital transformation should not be the adoption of technology but governance, cultural, and capability building.

In short, the discussion of results proves that the digital twins can be used to transform the contemporary supply chains, yet its effect is preconditioned by the facilitating and hindering factors. These findings form a basis of the further discussion on theoretical and managerial implications in the following sections.

5.2 COMPARISON WITH EXISTING LITERATURE

This part is a critical comparison of the empirical results of this study with the current body of literature in Chapter 2. The aim of the research is to test how the results could confirm, or refute, and/or expand existing theoretical views on digital twin technology, supply chain resilience, and sustainability.

To offer a systematic picture of this comparison, Figure 5.1 shows how empirical results were in line with important theoretical constructs.

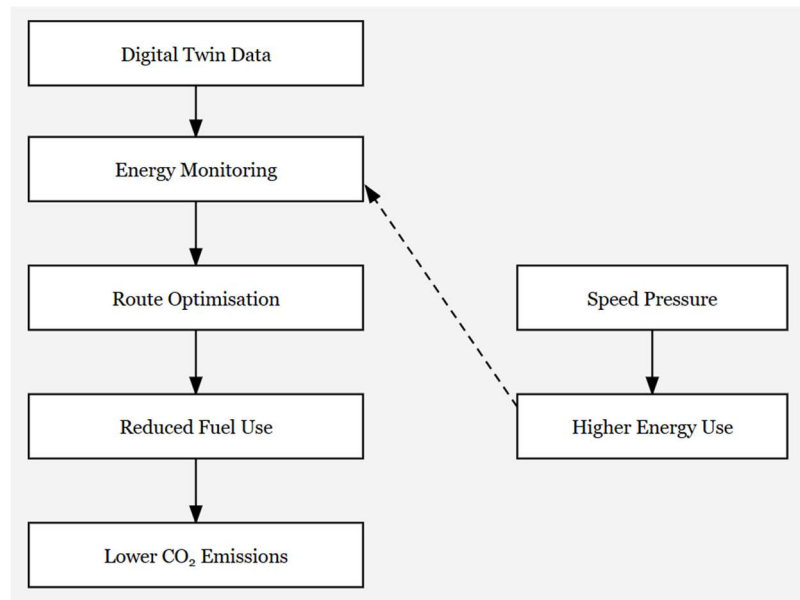


Figure 5.1: Digital Twin Influence on Sustainability Outcomes
(Source: Developed by the authors (2026))

The results indicate that there is a high level of conformity to the established theoretical models, especially regarding the ability of digital twins, resilience processes, and sustainability performance as demonstrated in Figure 5.1. Nonetheless, the discussion also shows that there are a few areas that empirical data goes far or refutes the assumed presumptions.

To enhance this graphical representation Table 5.1 offers an organized comparison of empirical results with the available literature.

Theme	Empirical Findings	Literature Alignment
Resilience	Real-time visibility and predictive modelling enhance disruption response and improve decision-making.	Supports Ivanov & Dolgui (2020); extends the role of organisational factors in resilience.
Sustainability	Efficiency improvements reduce emissions, but involve trade-offs between cost, speed, and environmental performance.	Aligns with Tao et al. (2019); challenges assumption that digital twins automatically ensure sustainability.
Implementation Challenges	Data integration, system complexity, and organisational resistance affect effectiveness.	Supports Fuller et al. (2020); reinforces sociotechnical perspective.
Strategic Value	Digital twins enable adaptive and data-driven decision-making capabilities.	Aligns with Teece (2007); extends application of dynamic capabilities.

Table 5.1: Comparison of Empirical Findings with Existing Literature
(Source: Developed by the authors based on empirical findings and literature (2026))

As indicated in Table 5.1, the results support as well as broaden the theoretical standpoints that exist especially regarding the issues of resilience, sustainability, and implementation.

5.2.1 COMPARISON WITH LITERATURE ON SUPPLY CHAIN RESILIENCE

The results are in close correspondence to the current studies that recognize digital twin technology as one of the most powerful tools towards supply chain resilience due to its ability to promote visibility, predictive modelling, and real-time decision-making (Ivanov and Dolgui, 2020; Christopher and Peck, 2004).

In line with the literature, the empirical findings prove that digital twins help organisations predict disruptions and act proactively in response to them. This supports the idea of resilience as a dynamic capability with sensemaking, reaction and recovery to disturbances.

Nonetheless, the results are relevant to the current body of literature in that they indicate that resilience does not necessarily rely on technological competencies. Rather, organisational aspects like governance forms, decision making, and data interpretation is significant in finding out how well digital twin's systems are. This implies that resilience is more to be viewed as a social-technical ability, and not as a technological achievement.

5.2.2 COMPARISON WITH LITERATURE ON SUSTAINABILITY

The results can be compared to the current literature that places the digital twin technology as an instrument to enhance the sustainability by maximising efficiency and resource utilisation (Tao et al., 2019; Kamble et al., 2020).

The results of this study are supported by the empirical evidence, which proves that digital twins promote sustainability through optimisation of transportation routes, minimisation of waste and enhancement of resource utilisation. These results support the thesis that digital technologies can also help to achieve environmental performance in terms of operational efficiency.

But the outcomes also refute the idea that digital twins automatically result in the enhancement in sustainability. The trade-offs between cost, speed, and environmental goals imply that the sustainability outcomes are related to the organisational priorities and decision-making processes. This builds upon the body of literature by showing how digital twins offer the facility of sustainability, and not its actualisation.

5.2.3 COMPARISON WITH SOCIOTECHNICAL PERSPECTIVES

The results are highly persuasive of sociotechnical theory which focuses on the interplay of the technological systems and organisational structures (Bostrom and Heinen, 1977).

The problems of data integration, system complexity, and organisational resistance that have been identified in this paper demonstrate the significance of using the technological solutions in line with human and organisational aspects. These results prove that digital twin systems cannot be functional in lone mode, but they should be implemented in greater organisational frameworks.

Additionally, the paper builds upon sociotechnical theory by demonstrating the ways of how digital twin technologies present novel complexity and dependence in the sphere of supply chains. It indicates that organisations need to acquire new competences that will help them deal with the interface between the digitised systems and operational processes.

5.2.4 COMPARISON WITH DYNAMIC CAPABILITIES THEORY

The results are rather consistent with the Dynamic Capabilities Framework that focuses on the capacity of an organisation to sense, exploit and redesign their resources to adjust to the changing environment (Teece, 2007).

The digital twin technology can facilitate these functions through the ability to monitor (sensing), make decisions grounded on the data (seizing), and modify the operations (reconfiguring) in real-time. This supports the concept of digital twins as strategic organisations who enable the agility and resilience of organisations.

Nonetheless, the results also stretch this framework by showing that the formation of the dynamic capabilities via the digital twin technology implies a considerable investment into the infrastructure, data systems, and organisational alignment. This shows how digital transformation is resource-intensive and that strategic planning in the development of capabilities is crucial.

5.2.5 SYNTHESIS OF COMPARATIVE INSIGHTS

All in all, the literature comparison shows that the results largely justify the current theoretical view about digital twin technology, specifically about resilience and operational efficiency.

Meanwhile, the research can be relevant to the literature in that it emphasizes the role of organisational and strategic variables in the effectiveness of digital twin systems. These findings imply that digital twins are supposed to be thought of as socio-technical and strategic systems, and not as technological tools.

This combined approach can be an in-depth view of how digital twin technology can be applied in complex supply chain conditions and a basis of further theoretical and practical evolution.

5.3 THEORETICAL IMPLICATIONS

This part of the paper presents the theoretical contributions of the research by discussing the extension, refinement, and contribution of the findings to the current academic contexts associated with digital twin technology, supply chain resilience, and sustainability. The analysis is based on the literature analysed in Chapter 2 and empirical evidence provided in Chapters 4 and 5.

To depict theoretical contributions of the study, Figure 5.2 demonstrates the conceptualised relationship of digital twin capabilities, resilience, sustainability, and organisational factors.

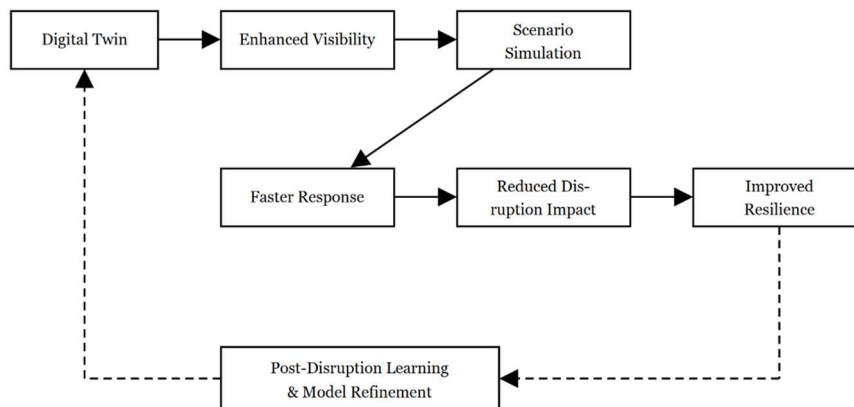


Figure 5.2: Mechanism Through Which Digital Twins Enhance Supply Chain Resilience

(Source: Developed by the authors (2026))

Figure 5.2 illustrates that digital twin technology is part of wider socio-technical system, whereby technological capabilities are interplaying with organisational and strategic factors to determine the result of resilience and sustainability. This sophisticated model underscores the relationship and continually changing aspects of digital change in supply chain settings

5.3.1 CONTRIBUTION TO DIGITAL TWIN THEORY

The results add to the theory of digital twins by supporting the conceptualisation of digital twins being dynamic, data-driven systems that can be used to monitor, simulate, and optimise in real time (Tao et al., 2019).

But this research goes beyond the current theory to show that digital twins are more of decision-support systems than autonomous technologies. Whereas, previous studies tend to focus on the technical potential of digital twins, the results of the empirical research point to the role of organisational interpretation, governance, and decision-making in defining their success.

It indicates that the notion of digital twin theory must integrate a more powerful emphasis on the interaction between technical abilities and human decision-making, thus becoming more of an integrated socio-technical concept instead of a technical one.

5.3.2 CONTRIBUTION TO SUPPLY CHAIN RESILIENCE THEORY

The research adds to the study of the resilience theory of supply chains by offering empirical support to the impact of digital twin technologies on resilience by means of predictive modelling, scenario simulation, and real-time responsiveness.

In line with the available models (Christopher and Peck, 2004; Ivanov and Dolgui, 2020), the results prove that resilience entails the capacity to foresee, act on, and recuperate disruptions. This view is taken further in the study, though, as it shows that digital twins can be used not only to create proactive resilience (by predicting and simulating) but also to create adaptive resilience (by changing how an operation is run in real-time).

In addition, the results also point out the fact that resilience depends not only on technological capability but also organisational issues like data quality, governance, and decision-making processes. It provides a case in favour of viewing resilience as a socio-technical capability, which combines the technological and organisational aspects.

5.3.3 CONTRIBUTION TO SUSTAINABILITY THEORY

The results add to the sustainability theory by demonstrating how the digital twin technologies promote environmental performance by ensuring operational efficiency and resource optimisation.

Although the current body of knowledge focuses on the promise of digital technologies to enhance the volume outcomes of sustainability (Geissdoerfer et al., 2017; Kamble et al., 2020), this research offers empirical insights into how this advantage is realised in practice in complex supply chains.

Significantly, the results are relevant to the existing body of knowledge, as they demonstrate that there are trade-offs between sustainability, cost, and service performance. This implies that sustainability outcomes do not automatically accompany the adoption of technology, but they depend on organisational priorities and strategic choices.

The insight is part of the current discussions on how to relate efficiency and sustainability, meaning that digital twins can facilitate sustainability yet are not necessarily focused on it.

5.3.4 CONTRIBUTION TO SOCIOTECHNICAL SYSTEMS THEORY

The research contributes greatly to sociotechnical systems theory through the illustration of the reliance of digital twin's implementation on the interaction between technological systems and organisational structures (Bostrom & Heinen, 1977).

The results emphasise that data integration, system complexity, and organisational resistance are not exactly technical issues but are well entrenched issues in organisational set-ups. This reaffirms the topicality of sociotechnical theory in comprehending digital transformation in supply chains.

Also, the work builds on the sociotechnical theory by demonstrating that digital twins bring a new type of complexity and interdependence, and organisations should build the ability to manage technology change and organisational change in parallel.

5.3.5 CONTRIBUTION TO DYNAMIC CAPABILITIES THEORY

They also add to the Dynamic Capabilities Framework since the results reveal how digital twin technology can help an organisation sense, seize, and reconfigure its resources in response to environmental shifts (Teece, 2007).

Digital twins expand the scope of sensing by enabling real-time data visibility, capture capabilities by utilizing data insights in decision-making and reconfig capability by adjusting operations in real-time. This supports the position of digital technologies as facilitators of organisational agility and resilience.

Nonetheless, the research will further expand this framework by noting that the formation of these capabilities consumes a massive amount of data infrastructure, organisational alignment and strategic planning. This implies that the dynamic capabilities are not created spontaneously by adoption of technology but are developed and managed.

5.3.6 SYNTHESIS OF THEORETICAL CONTRIBUTIONS

The study, in general, can add up to the existing body of knowledge as it incorporates the theory of digital twins, resilience theory, sociotechnical perspectives, and sustainability theory into a coherent framework.

The results indicate that the digital twin technology must be perceived as a component of a complicated socio-technical system, with technological opportunities and organisational and

strategic aspects interplay to influence the results. This combined view offers a more holistic view of the digital transformation of supply chains and demonstrates that future studies require interdisciplinary approaches.

5.4 MANAGERIAL IMPLICATIONS

This section describes the implications of the research findings to managers and practitioners working in the sphere of supply chain management, digital transformation, and sustainability programs. The experiences gained in the Amazon case study and the interviews with experts help to make suggestions on how organisations can successfully apply the digital twin technology to improve operational performance.

5.4.1 ENHANCING SUPPLY CHAIN VISIBILITY AND DECISION-MAKING

The results show that real-time visibility can be crucial in enhancing supply chain performance. Focus of managers should be on the creation of integrated systems of data that allow constant monitoring of activities within the fulfilment centres, transportation networks, and inventory systems.

Digital twin technologies may be implemented to develop integrated platforms that bring together the information across various sources and make better and timely decisions. Nonetheless, managers should also be able to make sure that proper governance frameworks are established to convert data insights into useful operational measures. This involves setting up of clear decision-making processes and accountability structures.

5.4.2 STRENGTHENING SUPPLY CHAIN RESILIENCE

This paper will show that digital twins have a strong potential to improve resilience by utilizing predictive modelling and scenario simulation. Managers are to use these capabilities actively to detect possible disruptions and assess alternative response plans.

Practically, this entails incorporating digital twin systems into the risk management procedures and applying them to stress-test the supply chain networks in various conditions. Nonetheless, organisations must not be too dependent on digital models and make sure that human judgement is part and parcel of making decisions.

5.4.3 LEVERAGING DIGITAL TWINS FOR SUSTAINABILITY

The use of digital twin's technology can be applied to enhance the concepts of sustainability by optimisation of transportation pathways, waste reduction and enhancement of operational efficiency. Digital twins should be applied by managers to attain an analysis of the environmental impacts in addition to traditional performance measures like cost and service levels.

Nonetheless, the results have shown that organisational priorities affect sustainability outcomes. Thus, to achieve the goals of sustainability, managers have to be engaged in utilizing sustainability goals in the strategies of decision making instead of believing that technological adoption will present all the environmental gains.

5.4.4 ADDRESSING IMPLEMENTATION CHALLENGES

Digital twin implementation has several challenges such as data integration problems, complexity, and high cost. Managers need to implement it in phases, with pilot projects that will be used to initially test and refine digital twin applications and then scale them to the organisation.

Also, organisations need to invest in data governance structures that will make data accurate, consistent, and interoperable between systems. Skill and training are also necessary to help the employees have the capabilities of using digital twins effectively.

5.4.5 STRATEGIC AND ORGANISATIONAL CONSIDERATIONS

The results highlight that the implementation of a digital twin is not an exclusively technological project, but a larger organisational change. Managers are expected to synchronise digital twin strategies with organisational objectives, whereby technology adoption aids organisational objectives of operational efficiency as well as long-term strategies.

Additionally, IT, operations, and sustainability teams should work closely cross-functionally to make the most of digital twin systems. Organisations are also advised to promote a culture of innovation and databasing decision-making.

5.4.6 SUMMARY OF MANAGERIAL IMPLICATIONS

In general, the results indicate that digital twin technology can be a source of considerable value in the aspects of resilience, sustainability, and operational efficiency. These advantages, however, depend on proper implementation, organisational alignment and strategic integration. Managers should hence take a holistic view that brings into consideration the technological, organisational and strategic sides to realise the full potential of the digital twin systems.

5.5 REVISED CONCEPTUAL FRAMEWORK

According to the obtained empirical data and its comparative analysis with the available literature, the current research suggests a modified conceptual framework that looks at the role of digital twin technology in improving the resilience and sustainability of the supply chain in the complex organisational settings.

The first conceptual framework introduced in Chapter 2 was concerned mostly with the direct connection between the digital twin capabilities and the supply chain outcomes. The results of this research, however, point to the fact that this relationship is more complicated and also depends on other organisational and strategic factors.

Figure 5.3 shows the refined conceptual framework that was created off of the study to demonstrate these fine-tuned relationships.

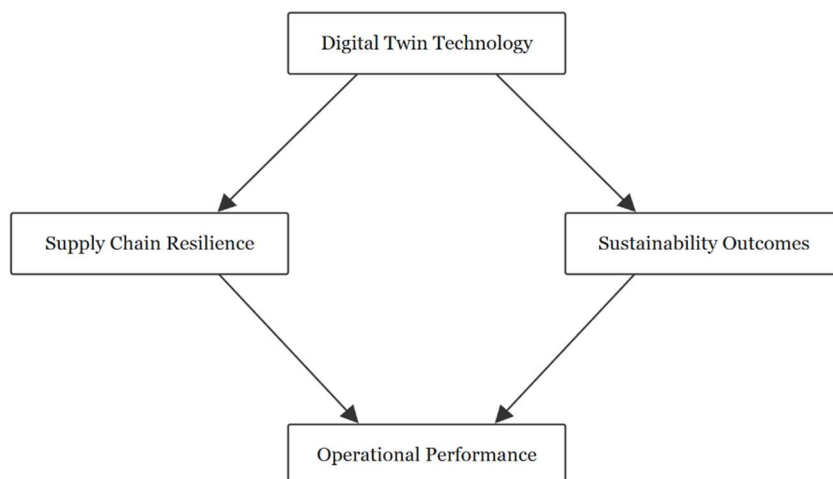


Figure 5.3: Revised Conceptual Framework
(Source: Developed by the authors (2026))

According to Figure 5.3, the updated framework puts digital twin technology at the centre of the system, which explains its importance to provide the real-time visibility, predictive modelling, and simulation of scenarios (Tao et al., 2019; Ivanov and Dolgui, 2020).

Nonetheless, the updated framework adds organisational and strategic elements to the model, including governance, data quality, and decision-making to the list of the most important mediating factors, which determine the success of the digital twin implementation. This is in line with the empirical observation which shows that technological capability is not enough to drive desired results.

The framework also explains how dual the influence of digital twin technology on the supply chain resilience and sustainability is, as it shows that they are not independent but mutually dependent. Both resilience and environmental performance are increased as a result of operational efficiency and risk management.

The model is also revised to include implementation issues, such as data integration, complexities, and scalability limitations of the system as moderating variables that may restrict the efficacy of digital twin systems. This addition represents the empirical practical barriers in the empirical findings and expands the prior theoretical models.

Notably, the framework also places focus on the fact that digital twins are decision-support systems in a socio-technical environment, and not entirely autonomous technologies. This is in line with sociotechnical systems theory (Bostrom and Heinen, 1977) and the Dynamic Capabilities Framework, which puts emphasis on organisational capability to sense, seize, and reconfigure resources (Teece, 2007).

5.5.1 KEY CONTRIBUTIONS OF THE REVISED FRAMEWORK

The updated conceptual framework adds to the existing literature in a number of ways.

First, it expands the digital twin theory by incorporating technological, organisational, and strategic levels into a single model. This gives a deeper insight into the way digital twin systems work in the real-world supply chain settings.

Second, it emphasises the interrelatedness of resilience and sustainability and shows that these two outcomes are not determined by independent processes but are interconnected through underlying capabilities.

Third, the framework presents a socio-technical approach, which notes that the success of digital twin technology relies on the agreement between digital systems and organisational structures.

Lastly, the presence of implementation issues makes the adoption of digital twins look more realistic, which is a limitation of the current literature, where almost all authors discuss the advantages of technology.

5.5.2 IMPLICATIONS OF THE FRAMEWORK

The new framework has theoretical and practical implications. Theoretically, it establishes a base of future studies concerning the digital twin technology in managing supply chains by emphasizing the need to combine various lenses.

Practically speaking, the framework can inform organisations to design and establish digital twin systems in a more efficient way. It stresses the importance of integrating technology with organisational processes, strategic objectives and sustainability goals.

5.5.3 DYNAMIC FEEDBACK LOOPS

Another important change to the conceptual framework revised is the inclusion of dynamic loops of feedback. The results reveal that digital twins systems cannot be perceived as fixed tools, but they are learning systems that are constantly developed using operational data, managerial interpretation, and organisational adaptation. This point of view is in line with the thinking of digital twins as dynamic information-based systems that facilitate continuous improvement instead of a single-point optimum (Tao et al., 2019).

The feedback loops that have been identified in this study are at various levels. To start with, operational performance that results in responses to disruptions, service performance, and sustainability measures yield data that can be recirculated in the digital twin system to enhance model performance and scenario simulation. Second, interpretation of this data aids learning in organisations enabling managers to perfect processes, decision rules and alter strategic priorities as time goes by. Third, the changes affect the future operational and thus an operating pattern is developed to create a cycle of digitally understanding something and putting it to practical use.

This dynamic viewpoint builds upon the existing literature by demonstrating that digital twin capabilities can be used to facilitate not only the real-time decision-making process, but also

organizational learning and adaptation. Here, the digital twins are resilient and sustainable in that they not only enhance the operational efficiencies in the short term, but also in the long term by enabling them to enhance the adaptive capacity. This explanation is close with the Dynamic Capabilities Framework especially the sensing, seizing and reconfiguring in reaction to the environmental change (Teece, 2007).

5.5.4 TEXTUAL REPRESENTATION OF THE FRAMEWORK

To make the structure of the conceptual model changed clearer, Figure 5.4 demonstrates the textual image of the framework between digital twin capabilities and the outcomes of resilience and sustainability.

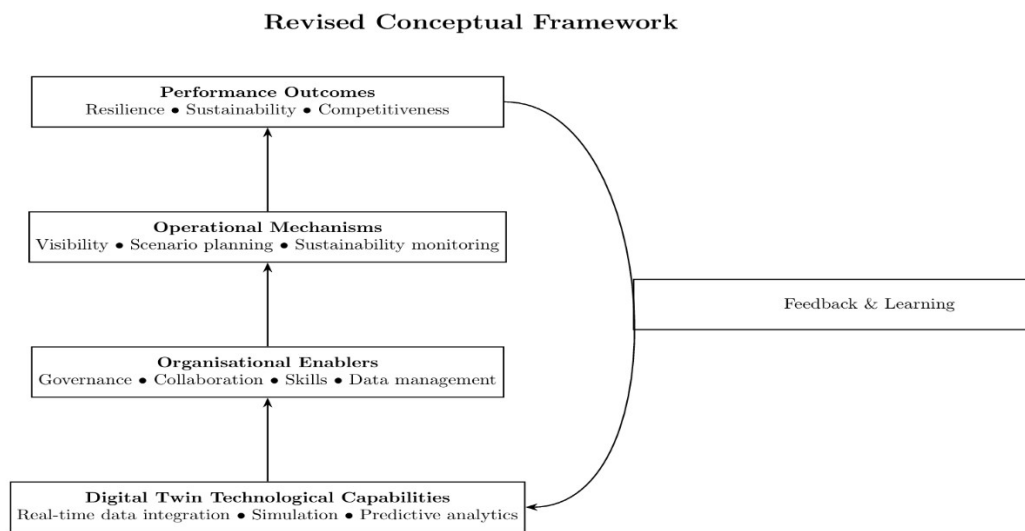


Figure 5.4: Revised conceptual framework linking digital twin capabilities with resilience and sustainability outcomes
(Source: Developed by the authors (2026))

As illustrated in Figure 5.4, the framework starts with the core capabilities of digital twins such as real time data integration, predictive modelling, simulation and optimisation tools. Such technological competencies constitute the base layer of the model and offer the analysis foundation of decision support and scenario analysis (Ivanov and Dolgui, 2020; Tao et al., 2019).

The second layer is comprised of organisational enablers such as leadership commitment, cross-functional collaboration, digital skills, interoperability and data governance. The results show that these variables mediate the degree of translation of technological capabilities into

practical value. That is, the digital twin systems are not only creating insights, but organisations need to have the internal structures and capabilities to interpret and use them effectively.

The third layer reflects the working processes by which the digital twin systems impact the performance of the supply chains. The latter are the increased visibility, ability to simulate disruption, more reactive decision-making and incorporating the sustainability aspect into operational planning. These processes serve as the intermediary between the technology and the performance of organisations.

The framework presents three dimensions at the outcome level, which are interrelated, and these are supply chain resilience, sustainability performance, and strategic competitiveness. These outcomes support each other, instead of working separately. To illustrate, enhanced resilience minimises inefficiencies and waste, whereas the sustainability-based optimisation can reinforce the robustness of the operations in the long term.

Lastly, the framework includes active feedback mechanisms that will link the performance outcomes to the technological and organisational layers. These are just some of the loops that prove that digital twin systems promote continuous learning, model improvement, and strategic adjustment. This written expression can thus enhance the claim that digital twins are installed socio-technical systems as opposed to solitary digital appliances (Bostrom and Heinen, 1977).

5.5.5 CONTRIBUTION OF THE REVISED FRAMEWORK

The new conceptual framework offers to the study several contributions.

To begin with, it is more inclusive of the digital twin implementation as it combines technological, organisational, and strategic aspects into one explanatory model. It adds to existing literature on digital twin's literature which tends to place more emphasis on technological functionality, demonstrating that organisational enablers are as important as the former in determining performance outcomes (Tao et al., 2019; Fuller et al., 2020).

Second, the framework contributes to the knowledge about the connection between resilience and sustainability by showing that the two outcomes do not focus on different, conflicting achievements, but are two related dimensions that are affected by overlapping capabilities and processes. This adds to the accumulating evidence that operational resilience and environmental performance can be self-reinforcing with the assistance of the digital technologies (Ivanov and Dolgui, 2020).

Third, the framework adds to the sociotechnical systems theory by demonstrating that effectiveness of digital twin systems is tied to the alignment of digital infrastructure, organisational processes, and human decision-making. This supports the significance of considering digital transformation as an organisational change process as opposed to an upgrade that is more technical based (Bostrom and Heinen, 1977).

Fourth, the model enhances the utilization of the Dynamic Capabilities Framework by demonstrating how digital twin technologies facilitate sensing, seizing and reconfiguring operations of real-world supply chain contexts (Teece, 2007). By so doing, it gives a better description of the way in which digital technologies can be transformed into adaptive and strategic organisational competencies.

In general, the updated framework provides a theoretical and practical roadmap. It is a refinement of existing models, theoretically, by adding mediating variables of organisations and feedback. In practice, it offers managers a guided approach of comprehending how the digital twin potential can be utilized to enhance resilience, sustainability, and competitiveness in the long run.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 SUMMARY OF THE RESEARCH

In this dissertation, the study of digital twin technology in increasing supply chain resilience and sustainability was being conducted with a detailed case study of Amazon. The study has been driven by the fact that global supply chains are becoming increasingly complex and vulnerable, and organisations are under pressure to do better in environmental performance. Even though the concept of digital twin is currently extensively discussed as a radical innovation, there is a lack of empirical evidence on how it would be used in large-scale logistics systems.

The key purpose of the research was to examine how digital twin's systems could be used to enhance resilience and facilitate sustainability of complex supply chains networks. To fulfil this purpose, three research questions were followed, which were the role of digital twins in managing disruption, sustainability and carbon reduction, and organisational challenge of implementation.

The qualitative and exploratory research design was followed with interpretivist and pragmatic philosophical approaches being the basis. The semi-structured interviews with three domain experts were used to collect the data, which was supplemented by secondary sources. Thematic analysis was employed to recognize the trends in the information and to combine the obtained empirical data with the previously developed theoretical framework that will allow gaining the complete vision of both operational and theoretical aspects.

The results prove that digital twin technology can greatly increase supply chain visibility, facilitate the use of scenarios to decide, and introduce sustainability metrics into the working process. These are capabilities that enable organisations to model disruptions, optimise logistics performance and make better environmental trade-offs. Nevertheless, the research also states that organisational factors play a key role in defining the effectiveness of digital twins such as its governance structure, data quality management, and workforce capabilities.

Based on these observations, the research developed a modified theoretical framework, which places digital twins in the role of sociotechnical systems in the dynamics of organisational

environments. The framework encompasses the interplay among the technological capabilities, organisational enablers, operational processes and performance outcomes, and focuses on the constant learning and feedback mechanisms.

In sum, the study adds to the scholarly and practical knowledge by showing that the concept of digital twin technology should be regarded as one of the strategic organisational capabilities, which facilitate adaptive, resilient, and sustainable supply chain management.

6.2 KEY CONCLUSIONS

In this section, the main findings of this study are given, as it provides answers to the research questions directly and summarizes the main findings based on the results of the empirical research and theoretical discussion.

Table 6.1 summarises the key findings in line with the objectives of the study to provide a systematic picture of the relationship between the results and the answers to the research questions.

Research Question	Key Finding	Theoretical Contribution	Practical Contribution
RQ1: How do digital twins enhance supply chain resilience?	Digital twins improve resilience through real-time visibility and scenario simulation, enabling adaptive responses to disruptions.	Extends Dynamic Capabilities Theory by demonstrating how digital twins function as sensing and reconfiguration mechanisms in high-velocity supply chains.	Supports disruption preparedness through predictive modelling, stress testing, and enhanced decision support.
RQ2: How do digital twins support sustainability and carbon reduction?	Digital twins enable monitoring of emissions, energy consumption, and logistics efficiency, though benefits depend on strategic prioritisation.	Links digital twin capabilities to sustainable supply chain performance measurement, integrating environmental metrics into operational theory.	Facilitates carbon tracking, energy optimisation, and data-driven sustainability decision-making.
RQ3: What challenges influence digital twin implementation?	Implementation success depends on data integration quality, system complexity management, and organisational culture.	Refines the Resource-Based View by identifying digital infrastructure and data capabilities as strategic organisational assets.	Highlights the importance of leadership commitment, employee training, and cross-functional collaboration.

Table 6.1: Summary of Key Contributions of the Study

(Source: Developed by the authors (2026))

The results presented in Table 6.1 reveal a high correspondence between the digital twin potentials and the enhancement of supply chain resilience and sustainability, as well as indicates the main implementation issues and organisational factors to consider.

CONCLUSION IN RELATION TO RQ1: DIGITAL TWINS AND SUPPLY CHAIN RESILIENCE

This paper validates the importance of digital twin technology in improving the resilience of the supply chain by allowing real-time tracking, predictive modelling, and decision-making based on scenarios. The results show that digital twins enable organisations to predict disruptions, assess other options, and react more efficiently to operational uncertainties.

This finding aligns with the current literature, which identifies the use of digital technologies to facilitate proactive risk handling and adaptive supply chain responses (Ivanov and Dolgui, 2020; Christopher and Peck, 2004). Nevertheless, the research goes further to show that resilience is not entirely based on technological capability. In its stead, organisational influence on the success of digital twin systems is considerable and includes the quality of governance, data, and decision-making.

CONCLUSION IN RELATION TO RQ2: DIGITAL TWINS AND SUSTAINABILITY OUTCOMES

The paper concludes that the digital twin technology can help in the sustainability process mainly in terms of operational efficiency, such as optimization of transportation, inventory management, and resource utilisation. The abilities contribute to the minimization of carbon emissions and improve the overall environmental performance.

This is in line with previous studies focusing on the effect of digital technologies in enhancing sustainability performance (Tao et al., 2019; Kamble et al., 2020). Nevertheless, the results show that the sustainability will not be a natural side effect of using digital twins. Rather, it relies on organisational priorities and the level at which the consideration of the environment is incorporated in the decision-making process.

Moreover, the paper reports the existence of trade-offs among cost, speed, and sustainability indicating that organisations should pursue the equilibrium of opposing demands proactively to ensure the attainment of significant environmental results.

CONCLUSION IN RELATION TO RQ3: IMPLEMENTATION CHALLENGES AND OPPORTUNITIES

The paper determines that several challenges tied to the adoption of digital twin technology, such as data integration, system complexity, and scalability limitations, and organisational resistance toward change.

Such results strengthen the available body of research on obstacles to supply chain digitalization (Ivanov and Dolgui, 2020; Fuller et al., 2020). Simultaneously, the paper also points to the fact that these difficulties remain not entirely technical but are rather integrated into bigger organisational and strategic frameworks.

Notably, the opportunities linked to the adoption of digital twins also include the use of digital twins to make decisions based on more data, enhance operational efficiency, and facilitate long-term strategic capability, as mentioned in the study. This implies that the implementation hurdles are a big issue, but they can be overcome through proper planning, investment, and organisational alignment.

OVERALL CONCLUSION

Overall, this paper shows that the digital twin could be greatly used to increase supply chain resilience and sustainability in the complicated network of logistics like the one in Amazon. Its success however depends on how technological capabilities are incorporated within organisational operations and strategic goals.

As the findings emphasize, digital twins are to be perceived as socio-technical systems, in which technology, human judgement, and organisational frameworks interface to influence the results. The school of thought offers a more detailed view of change in supply chains through digital transformation and supports the necessity of a holistic approach to the implementation

6.3 RECOMMENDATIONS

On the results of the present research, there are several practical recommendations that are suggested to organisations aiming to adopt digital twin technology to achieve supply chain resilience and sustainability. Such suggestions are especially applicable in large-scale logistics systems like Amazon, and they indicate the main challenges and opportunities found in the study.

6.3.1 STRATEGIC AND OPERATIONAL RECOMMENDATIONS

The main concern of organisations should be the creation of built-in data infrastructure to facilitate digital twin systems due to its reliance on the quality and access to real-time data. It entails the creation of standardized data systems which link fulfilment centres, transportation and inventory chains.

Moreover, the digital twin technology must be integrated into the basic decision-making processes instead of being viewed as an independent analytical tool. Scenario planning, disruption management, and operational optimisation are three areas that managers must leverage digital twins by making sure that the insights that digital twins provide are converted to actionable decisions.

Moreover, organisations need to use the opportunities of digital twins to enhance the resilience of their supply chains by simulating and stress-testing logistics networks on a regular basis. Meanwhile, the digital twin initiatives are to be connected to the sustainability goals, with the environmental metrics in decision-making and the optimisation of resource use.

6.3.2 IMPLEMENTATION AND ORGANISATIONAL RECOMMENDATIONS

Since digital twin implementation is complex organisations must move at a slow pace, starting with pilot projects then expand throughout the supply chain. This enables technical and organisational challenges to be identified and risk is reduced.

Data governance frameworks that allow organisations to verify the accuracy, consistency and interoperability of data should also be invested by organisations. Simultaneously, it is important to build the capabilities of the workforce by training and developing skills to be able to use the digital twin systems.

Lastly, managers ought to understand that the digital twin implementation is a wider organisational change and not just a technological upgrade. This demands bold leadership, inter-departmental teamwork and a culture that elevates the use of data in making decisions and innovation.

6.4 FUTURE RESEARCH DIRECTIONS

Although the current work gives credible information on how digital twin technology can be used to improve supply chain resilience and sustainability, several weaknesses present potential

research gaps. The research was grounded on the qualitative methodology and few interviews with experts, and it mainly concentrated on Amazon as a case study. Though this allowed in-depth exploration, it causes restriction in the generalisability of the findings.

The future research may build on this study by following a quantitative or mixed research methodology to investigate the effects of digital twin technology on a wider range of organisations. The extensive empirical research would allow the investigators to confirm the correlations presented in this paper and determine quantifiable impacts of this research like operational performances, the measures of resilience, and carbon emissions. This would enhance the empirical base of the digital twin studies that are still limited in the large-scale real-world situations (Ivanov and Dolgui, 2020).

Moreover, the use of the digital twin technology in various industries and the supply chain system should be researched further. Although this paper has investigated a big e-commerce organisation, it is possible that other industries like manufacturing, healthcare, and retail have other challenges and opportunities. The comparative research of digital twins implementation in various organisational settings could allow gaining a more comprehensive view of the system application and determine industry-related factors that contribute to its success.

The second direction that could be followed in future research is the further analysis of the resilience-sustainability relationship. The results of this research indicate that these two goals are related but trade-offs are common among them especially in relation to cost, speed, and environmental performance. Future research might examine how organisations deal with these trade-offs and how digital twin systems might be used to help organisations make more balanced decisions. It would add to the current discussions in the literature about how sustainability can be integrated into the process of operations and strategies (Tao et al., 2019).

Additionally, this paper elaborates on the significance of organisational and sociotechnical aspects in the implementation of digital twins. The further study may be based on this finding to examine the impacts of organisational culture, leadership, and governance systems on the adoption and utilisation of digital twin systems. Specifically, it is necessary to investigate the role of digital twins in organisational learning and growth of capabilities throughout the time, which correlates with the Dynamic Capabilities Framework (Teece, 2007).

Lastly, the research carried out in the future might explore the combination of digital twin technology with other emerging technologies like artificial intelligence, Internet of Things

(IoT), and blockchain. The technologies could also increase the potential of digital twins and develop more developed and linked systems of supply chains. The discussion of these advances would be informative about the future of the digital twin technology and its involvement in influencing the next-generation supply chains.

6.5 REFLECTIONS ON THE RESEARCH PROCESS

This process of research has helped to gain significant knowledge on the academic and practical aspects of digital twin technology in the management of the supply chain. During the research, there were some major learning experiences, especially regarding the research design, data collection, and the possibility to combine theory and empirical results.

The need to follow a structured and systematic research approach was one of the greatest learning outcomes. Defining the research questions, choosing a proper methodology and carrying out a thematic analysis were the processes that had to be carefully planned and constantly improved. This experience helped the researchers to be more critical of information and find the related patterns and form the coherent arguments based on the theory and empirical data.

The semi-structured interviews as the main source of data collection offered a rich source of information on the actual practices and issues in the implementation of digital twins. But, the fact that the sample size was small also indicated the limitations of qualitative research especially on generalisability. This highlighted the need to supplement qualitative information with a larger body of empirical evidence in further studies.

The other important reflection can relate to the complexity of the digital twin technology itself. Although the idea of the research was operationalised as rather technical solution, it turned out that the organisational factors like the data governance, workforce capabilities, and decision-making structures play a critical role in determining its efficiency. This changed the perception of digital twins as a technological instrument and towards a wider socio-technical system entrenched in organisational environment.

Also brought to fore in the study was the issues related to the ability to balance multiple goals especially regarding resilience and sustainability. The results proved that both objectives should be met with a high level of consideration of trade-offs, which supports the role of strategic decisions in supply chain management.

Digital Twin in Supply Chain Resilience and Sustainability

Personally, and academically, this study has enhanced the abilities in critical thinking and writing skills as well as applying theoretical frameworks to practical issues. It also gave a better insight into the emerging technologies and the consequences of this to the contemporary supply chains.

Overall, the process of the research has been both hectic and satisfying and it has helped to form a more detailed and critical approach to the digital transformation within a supply chain management. The experience of this study is a good start in the academic and professional activities in this area.

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