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Enhancing Supply Chain Resilience Through Predictive Strategies and Innovation: A Path Toward Achieving Sdg9 (Industry, Innovation, and Infrastructure)

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Abstract:

This study aims to investigates how organizations can strengthen supply chain resilience in the face of disruptions while contributing to the realization of SDG 9 (Industry, Innovation, and Infrastructure). It aims to identify and evaluate predictive, data-driven, and innovative strategies that enhance operational continuity and industrial sustainability.

Grounded in the Resource-Based View (RBV), the Dynamic Capabilities Perspective (DCP), and Contingency Theory, the study explains how strategic resources, adaptive capabilities, and context-specific approaches collectively drive resilience in supply chains. A quantitative research design utilizing secondary data from 501 operational records with 13 variables was adopted. Descriptive, inferential, and logistic regression analyses were conducted to explore the relationship between disruptions, resilience-enhancing strategies, and performance outcomes.

The study findings reveal that preventive maintenance and inventory redundancy significantly improve delivery efficiency and resilience but involve cost trade-offs. Predictive modeling achieved 79% accuracy, demonstrating the value of analytics-driven forecasting in maintaining sustainable industrial infrastructure. The study underscores that integrating preventive maintenance, redundancy, and predictive analytics can advance resilient industrial systems, supporting SDG 9 targets for sustainable innovation and infrastructure. This research bridges theoretical and empirical insights, offering practical guidance for managers and policymakers on embedding resilience, innovation, and data intelligence into industrial and supply chain systems aligned with the SDGs.

Keywords: Supply chain resilience, SDG 9, predictive analytics, sustainable infrastructure, dynamic capabilities, preventive maintenance, industrial innovation.

1. Introduction:

The global supply chain environment has turned out to be more complex, intertwined and exposed to any kind of disruption. The COVID-19 pandemic, geopolitical conflicts, natural disasters, cyberattacks, and climate-related risks among others provided an understanding of how supply networks are vulnerable across industries. Organizations that previously depended on efficiency-based models like just-in-time production and lean inventory control are now faced with the fact that those models though economically efficient have not been flexible enough or able to provide redundancy levels required to absorb any unexpected shocks. Supply chain resilience has thus ceased to be a desirable quality but a strategic requirement of firms wishing to preserve continuity, safeguard stakeholder value and remain competitive in an uncertain business environment.

Supply chain resilience (SCRES) can be broadly understood as the capability of any system to predict, absorb, adapt, and survive disruptions and still deliver key functions and performance levels. As opposed to traditional ways of risk management, which are aimed at identifying and mitigating hazards, resilience focuses on flexibility and learning and building capacity in the organization to promote stability over time in the face of volatility. resilient supply chain construction, then, is a multidimensional process that entails strategic, operational, and relational processes that, together, define the extent to which organizations can respond to disruption situations.

This is because of the increasing rate and severity of disruptions, which underscore the urgency of the need to develop resilience. As one example, the pandemic led to unparalleled disruption in world supply chains, such as factory closures, transport jams, and a spike in demand of basic products. In the same manner, geopolitical turmoil like trade wars and sanctions have resulted in the impediments of supply and distribution, and natural catastrophes and climate-related issues are still disrupting supply chains. These upheavals have far-reaching economic and social impacts including high costs, stalemate production to loss of reputation and market share. The scale of such issues requires tactical reactions as well as building sound frameworks that combine theory to practice in order to inform the firms to enhance resiliency.

Even though there is an increased body of literature on supply chain resilience, there are still huge gaps. Much of the current research is compartmentalized, addressing individual industries and/or isolated case studies or limited collections of resilience practices. Not many studies have

come up with cohesive structures that combine several theoretical lenses besides offering empirical proofs. Additionally, as well as the large multinational corporations are usually prominent in the research on resilience, small and medium-sized enterprises (SME) are underrepresented, whereas these are vulnerable to disruption risks and have only unique resource constraints. The other limitation is that, there is relative deficiency of integration of technological and human aspects of resilience. Though artificial intelligence (AI), Internet of things (IoT), automation, and other technologies are crucial in increasing the predictive and adaptive ability, human factors like leadership, culture, communication, and collaboration equally determine the resilience outcomes.

This study adopts a quantitative research design based on secondary operational data from 501 supply chain records across various industries. The analysis applies descriptive, inferential, and predictive modeling techniques to evaluate resilience strategies. The research, based on the Resource-Based View (RBV), the Dynamic Capabilities Perspective (DCP), and the Contingency Theory, provides a deeper insight into the contribution of strategic resources, adaptive capabilities, and context-specific strategies to resilience in practice. The study includes the views of 100 supply chain experts in various industries and regions, which reflects both the statistical trends and the detailed information about how the organizations develop, introduce, and improve resilience practices.

This research has two objectives. To begin with, it seeks to further theoretical knowledge by incorporating various perspectives into a unified system, which explains the interaction of disruptions and resilience promoting strategies. Second, it aims at giving doable advice to the practitioners by highlighting best practices, success factors and the challenges related to developing resilient supply chains. In particular, the paper analyzes the following strategies, including the diversification of suppliers, redundancy of resources, the use of digital technology, cooperation with stakeholders, and the cultural alignment and evaluates their performance in reducing the effect of disruptions.

Positioning the concept of supply chain resilience within both the theoretical and practical realm, the study can be viewed as a contribution to the current academic debate and can be used to provide managers and policy-makers with evidence-based information. It highlights why organizations should not rest on reactive measures and start adopting resilience as a strategic requirement, which is bound to long-term planning, resource allocation, and organizational culture. In the end, the research gives companies a roadmap on how to enhance their resilience

capacity such that they are not only resilient enough to withstand disruptions but also have sustainable competitive advantage in a world that has been characterized by uncertainty and change.

1.1. Research Problem and Its Significance:

Although the resilience of supply chains has been widely discussed, there is also a rather scarce empirical literature in which the effect of predictive and data-driven approaches on industrial continuity and sustainability are quantitatively evaluated, especially in the framework of Sustainable Development Goal (SDG) 9, which calls for building resilient infrastructures and promoting sustainable industrialization. This research aims to fill this lack of awareness by focussing on the combined impact of preventive maintenance, redundancy and predictive analytics on overall supply chain performance.

Theoretically, the research is based on resilience theory, which focuses on the capacity of systems to anticipate, absorb and recover from disruptions by means of adaptive capacity. By incorporating data validation and predictive modeling into this structure, the research takes the theory further to contemporary industrial settings with digital transformation and uncertainty. Practically, the results would hopefully give industries an adaptive resilience framework, one that would be both cost-effective and data-driven to help them make proactive choices during disruptions. Such a framework can improve operational efficiency, reduce downtime, and ensure business continuity and contribute towards sustainable development. In all, this research helps close the gap between theoretical concept of resilience and its practical implementation to provide a way for industries to strengthen their infrastructure in order to achieve long-term sustainability.

1.2. Research Questions

1. How do disruptions affect supply chain resilience and operational performance?
2. What predictive and preventive strategies most significantly improve resilience outcomes?
3. How do resource-based and adaptive capabilities contribute to sustainable supply chain efficiency aligned with SDG 9?

2. Literature Review:

Commercial supply chain disruptions may have a big financial effect. Thus, there is a sense of urgency in managing supply chain risk and vulnerability. Resilience, defined as a system's ability to adjust to change and handle unexpected events while maintaining its fundamental structure and

functions (Yang et al., 2021), has become a crucial instrument for controlling supply chain risk and vulnerability (Ponis & Koronis, 2012). The emphasis of early supply chain resilience (SCRES) research was on resilience as an organizational characteristic that grants competitive advantage (Darabi, 2023) and as a way to reduce risk and vulnerability in supply chains (Monroe et al., 2014). According to that line of study, resilient supply chains may either recover from disturbances significantly more quickly or absorb them completely (Chowdhury & Quaddus, 2016). Additionally, studies have focused on characteristics that both increase and decrease supply chain resilience (Blackhurst et al., 2011), as well as tactics that businesses may employ to create resilient supply networks. New attempts to evaluate SCRES are being developed. For instance, the disruptive capacity was determined as the supply chain's recovery time after a disruption, and subsequent reviews have started to group research into typologies. This method yields what they refer to as the resilience index of a supply chain.

Defining Supply Chain Resilience:

In their paper "Supply Chain Management Resilience: A Theory Building Approach," Carvalho, Azevedo, and Cruz-Machado (2014) state that by putting forward a theoretical framework, their study advances knowledge of supply chain resilience. The goal of their study is to create a complete model that incorporates all of the variables that impact supply chain resilience. The authors emphasize the significance of resilience as a strategic imperative in today's changing business environment and want to provide a platform for future study and practical implementations in the area of supply chain management by relying on theoretical frameworks and empirical research (Carvalho et al., 2014).

In their work "The Importance of Supply Chain Resilience: An Empirical Investigation," Alfarsi, Lemke, and Yang (2019) state that they carried out empirical research to emphasize the importance of supply chain resilience. Their research offers useful insights into the ways that supply chain.

Resilience affects overall performance and company operations. By using data-driven research and actual case studies, the writers illuminate the tangible advantages of resilience tactics in reducing disruptions and improving supply chain effectiveness. The need for resilience in contemporary supply chains is emphasized in this study, as is its function in ensuring company continuity in an increasingly complicated and unpredictable corporate environment (Alfarsi et al., 2019).

The Importance of Supply Chain Resilience:

In the article "The Importance of Supply Chain Resilience: An Empirical Investigation," Alfarsi, Lemke, and Yang (2019) explore the critical component of supply chain resilience via empirical analysis. This report offers insights based on actual data and case studies, giving specific proof of the need for supply chain resilience. The authors emphasize the crucial role resilience plays in reducing disruptions and enhancing supply chain efficiency by outlining the practical consequences of resilience strategies on company operations and performance. Understanding the concrete advantages of resilience in maintaining company continuity in the complicated and unpredictable world of contemporary commerce is made easier with the help of this study (Alfarsi et al., 2019).

In Ponomarov and Holcomb's (2009) publication in The International Journal of Logistics Management, the writers provide a thorough examination of the notion of supply chain resilience in their work titled "Understanding the Concept of Supply Chain Resilience." Through an analysis of the concept's many aspects, components, and consequences, their study seeks to improve comprehension of this important idea. They shed light on the complexity of supply chain resilience and its applicability to operations and logistics via a thorough investigation. For scholars and industry professionals who want to learn more about supply chain resilience and how it affects modern supply chain management, this paper is a vital resource (Ponomarov & Holcomb, 2009).

Obstacles and Challenges in the Modern Business Landscape:

Young (2001) states that the author examines the corpus of information now available about the global business environment in the International Marketing Review article "What Do Researchers Know about the Global Business Environment?" The purpose of this study is to ascertain how well

Scholars now comprehend the intricate and ever-changing structure of international marketplaces. Young's research provides insightful analysis of the body of current knowledge by highlighting important developments, obstacles, and knowledge gaps regarding international business settings. This book offers a critical viewpoint on the state of knowledge in international marketing and business strategy, making it a vital resource for scholars and professionals in the business world who want to understand the subtleties of doing business globally (Yang et al., 2021).

Hung Lau and Zhang (2006) state that the authors examine the variables influencing outsourcing practices in China in their study "Drivers and Obstacles of Outsourcing Practices in China," which

was published in the International Journal of Physical Distribution & Logistics Management. This research explores the factors that encourage businesses to outsource, as well as the challenges they face along the way. Through an analysis of the distinct dynamics of the Chinese outsourcing environment, the writers provide significant perspectives on the intricate interactions influencing outsourcing choices and consequences within this geographic area. This study adds a great deal to our knowledge of Chinese outsourcing practices by illuminating the incentives and difficulties encountered by companies doing business in this major global outsourcing center (Hung Lau et al., 2006).

According to Brooks, Weatherston, and Wilkinson (2004), the writers of "The International Business Environment," a book that was released by Pearson Education, provide a thorough examination of the intricate and dynamic world of international business. This scholarly work explores the complex interplay of economic, political, cultural, and regulatory elements that affect global corporate operations. The writers provide readers with a comprehensive understanding of the global business landscape, enabling them to effectively manage the possibilities and difficulties it presents. For professionals, academics, and students who want to learn more about the complexities and dynamics of the global business world, this book is an invaluable resource (Brooks et al., 2010; Harrison, 2013).

Strategies for Dealing with Unexpected Disruptions:

Bhaskar (2018) states that the author of a doctorate dissertation at the University of Tasmania, "Managing Unexpected Disruptions: The Resilience of Shipping Companies," explores the Difficulties and methods that shipping businesses use to cope with unforeseen disruptions. This thorough investigation offers vital insights into the procedures, plans, and systems that the marine sector employs to guarantee operational resilience. Bhaskar's dissertation illuminates the intricate and dynamic realm of marine logistics and resilience, making a substantial addition to our knowledge of how shipping businesses handle and respond to unanticipated disturbances (Bhaskar, 2018).

The article "Business Disruptions and Affective Reactions: A Strategy-as-Practice Perspective on Fast Strategic Decision Making," which was published in Long Range Planning, Netz, Svensson, and Brundin (2020) examines how businesses respond to business disruptions, with a particular emphasis on the affective (emotional) reactions of individuals during the strategic decision-making process.

The research provides insights into how emotions and quick decision-making are critical for reacting to disruptions by using a strategy-as-practice viewpoint. Through the analysis of this dynamic, the study advances our knowledge of how companies handle unforeseen circumstances and strategically adjust to the fast-paced business climate of today (Netz et al., 2020).

In their work "Planning for Disruptions in Supply Chain Networks," which was included in the book "Models, Methods, and Applications for Innovative Decision Making" that was released by INFORMS, Snyder, Scaparra, Daskin, and Church (2006) state that the authors address the important subject of supply chain network planning with an emphasis on disruptions. The techniques and approaches for handling supply chain interruptions are examined in this chapter, emphasizing the need for proactive planning and decision-making. The writers provide a significant contribution to the subject of supply chain management by giving a thorough review of various planning techniques. This helps professionals and researchers better prepare for and lessen the effects of interruptions in intricate supply chain networks (Snyder et al., 2006).

Building Resilient Supply Chains: Tools and Tactics:

Mensah and Merkuryev (2014) state that the authors' emphasis in their paper "Developing a Resilient Supply Chain," which was published in Procedia-Social and Behavioral Sciences, is on robust supply chain development. Their study looks at methods and approaches that help.

Businesses create and manage supply networks that can survive unforeseen events. This study contributes to the field of supply chain management and business resilience by addressing a crucial aspect of supply chain resilience and providing insights into how businesses can improve their capacity to adjust, recuperate, and maintain operational continuity in the face of unforeseen challenges (Monroe et al., 2014).

The writers of Chauhan, Akram, and Chauhan's "Mapping Pathways for Building Resilient Supply Chains: A Systematic Literature Review" (2023) carry out a comprehensive analysis of the body of knowledge about supply chain resilience. The goal of this research is to provide a thorough review of the several approaches and tactics for improving supply chain resilience. The writers examine major topics, approaches, and findings from the literature by analyzing published research. As a result, they provide a useful tool for scholars and companies that want to comprehend and enhance supply chain resilience in a world that is changing quickly. It is anticipated that this systematic research will add to our understanding of supply chain resilience and its vital role in modern supply chain management (Chauhan et al., 2023).

Expected Outcomes of Resilience-Boosting Strategies:

Kemmerling (2022) states that the author probably presents a novel instrument for evaluating and quantifying resilience skills practice in his Ph.D. dissertation, "Development and Exploratory Factor Analysis of the Resilience Skills Practice Inventory," which he finished at William James College. With an emphasis on developing a trustworthy tool to assess how people participate in resilience-building activities and behaviors, this study most likely entails the development and validation of the Resilience Skills Practice Inventory. The study's exploratory factor analysis may shed light on underlying variables that support the use of resilience skills. This dissertation offers a systematic method for comprehending and evaluating resilience-building techniques, which may be of use to the fields of psychology and mental health. Nonetheless, the dissertation's whole text would provide precise information and conclusions (Kemmerling, 2022).

Tabibnia and Radecki (2018) said that they probably discuss the topic of how resilience training may affect the brain in their paper "Resilience Training That Can Change the Brain," which was published in the Consulting Psychology Journal: Practice and Research. The neurological and

Psychological components of treatments aimed at enhancing resilience are likely the focus of this study, which sheds information on the training programs' transformational potential. I don't have access to the whole book, but it's reasonable to believe that this study provides insightful information on the relationship between neuroscience and resilience training, which is pertinent to the fields of personal development and consulting psychology (Tabibnia et al., 2018).

Success Stories and Case Studies:

IBM's Hurricane-Resilient Supply Chain: Despite powerful storms like Katrina and Sandy, IBM was able to keep its supply chain running and guarantee the availability of essential parts. IBM demonstrated the effectiveness of resilience measures by swiftly adapting to supply chain interruptions and recovering by using real-time data analytics and supplier diversification.

Coca-Resilient Cola's Reaction to the COVID-19 Pandemic: Coca-Cola showed supply chain resilience during the COVID-19 epidemic by adjusting production and delivery to satisfy fluctuating customer needs. Utilizing sophisticated forecasting methods and risk management strategies, the corporation was able to ensure a steady supply of its goods.

Toyota's Adaptability During the 2011 Tsunami: Toyota's supply chain showed resilience in the wake of the horrific 2011 earthquake and tsunami that struck Japan. The firm demonstrated the

need for both agility and risk reduction by minimizing interruptions and recovering swiftly thanks to its lean production system and strong risk management approach.

Zara's nimble supply chain is well-known. Zara is a worldwide apparel store. By keeping manufacturing in-house, it can react swiftly to unanticipated occurrences and shifting fashion trends. This allows for fast alterations in reaction to market shifts and interruptions.

Sustainable Resilience at Unilever: Unilever has included sustainability in its plan for supply chain resilience. The organization mitigates risks associated with resource shortages and climate change by encouraging responsible sourcing and decreasing its environmental imprint. This approach provides long-term resilience.

Challenges in Implementing Resilience Strategies:

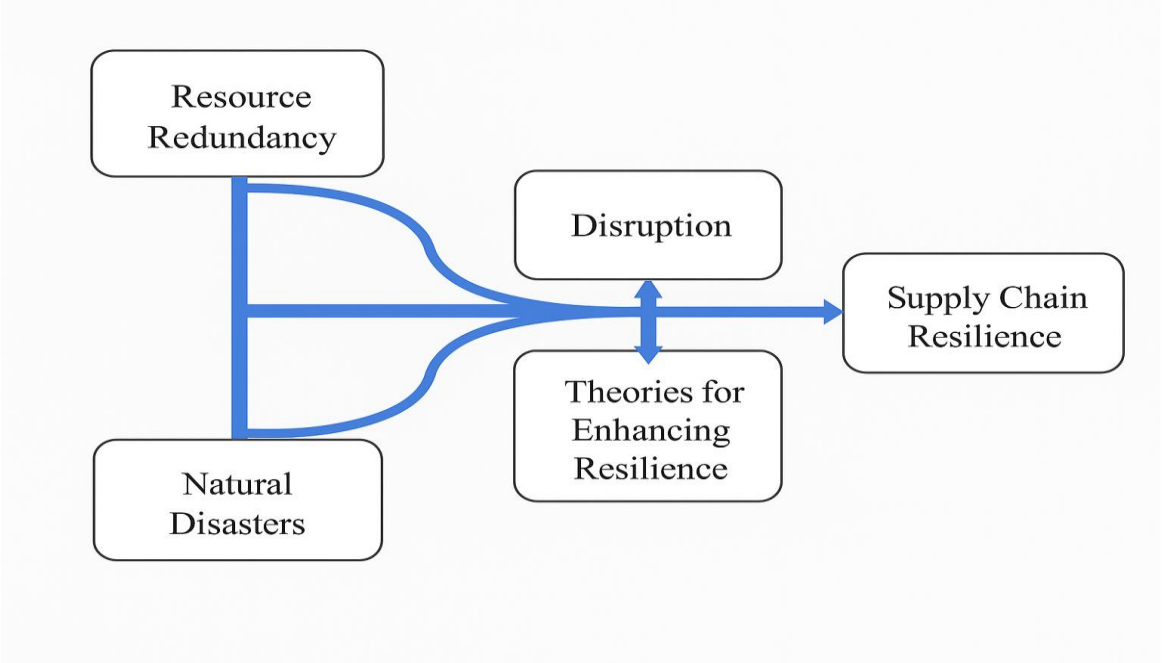
Using resilience measures in a supply chain comes with a number of difficulties. According to Lee et al. (2017), resource constraints—financial, technical, and human—often cause hindrances for businesses, especially smaller ones. As stated in Chopra and Meindl's study (2007), the complexity of current supply chains exacerbates the problem by making it difficult to oversee and safeguard each link in the chain due to various supplier levels, worldwide reach, and sophisticated logistics. As noted by Kleindorfer and Saad (2005), there are additional difficulties in obtaining timely and reliable data, which is essential for resilience, particularly in supply chains that span several systems and countries. Tang (2006) noted that it might be challenging to identify possible risks and vulnerabilities, especially when there are unusual or unexpected occurrences involved. Moreover, as Sheffi (2005) highlights, organizational resistance to change might impede its implementation. According to Wang et al. (2016), organizations often have to weigh the costs associated with resilience against the possible advantages in terms of risk mitigation and business continuity. As many academic works in the subject have noted, overcoming these obstacles calls for a comprehensive and cross-functional strategy that includes technology, open communication with suppliers, frequent risk assessments, and a culture change towards proactive risk management.

Theoretical Perspectives on Supply Chain Resilience:

The theoretical framework depicts the impact of supply chain resilience on two important dimensions disruptions and resilience-enhancing strategies. Natural disasters, economic shocks, and operational failures are some of the disruptive factors in supply chains, and resilience-

enhancing strategies, which are based on the Resource-Based View (RBV) or Dynamic Capabilities Perspective (DCP) and the Contingency Theory, empower them to avoid, absorb, and recover any such disruption. The RBV focuses on resource redundancy and preventive maintenance as fundamental resources of resilience; DCP focuses on adaptability and learning as a reaction to environmental change; and the Contingency Theory concerned that resilience plans should correspond to the situational contexts. These dimensions create a cohesive system where sustainability of supply chains is enhanced through predictive and adaptive practices, and sustainable industrial systems are achieved through the integration of these practices (SDG 9).

Figure 1. Conceptual Framework for Enhancing Supply Chain Resilience



Source: Author's creation

This figure illustrates the conceptual framework for enhancing the resilience of supply chains in the face of various disruptions, particularly natural disasters. The model demonstrates the role of resource redundancy as a proactive mechanism for mitigating the impacts of disruptions and improving adaptive and responsive capabilities.

It also highlights the interactive relationship between disruptions and theories supporting resilience. This framework contributes to supporting innovation and sustainable infrastructure, in line with Sustainable Development Goal 9 (SDG 9).

Literature gap

The lack of a thorough theoretical framework that unifies and synthesizes the various perspectives on how to improve supply chain resilience represents a clear research gap despite the increased understanding of the importance of supply chain resilience and the availability of numerous empirical studies and practical guidelines. The majority of the literature now in existence has concentrated on case-based analyses and useful tactics, often devoid of a methodical synthesis of ideas from many fields. This gap underscores the need for a more rigorous and theoretical approach that consolidates the existing knowledge and provides a structured framework to guide both academic research and practical implementations. By bridging this gap, future research can offer a more holistic and theoretically informed understanding of supply chain resilience enhancement, addressing the theoretical foundations that underpin these strategies and facilitating a deeper comprehension of the mechanisms at play during disruptions in supply chains."

1. While there are several case studies and practical approaches to supply chain resilience, there is a need for the development of comprehensive theoretical frameworks that integrate various factors affecting supply chain resilience. This gap highlights the need for more theoretical work in the field.
2. Disruptions to supply chains are becoming more frequent and dynamic due to various factors like climate change, political instability, and technological advancements. There is a need to explore how traditional supply chain resilience theories and models can adapt to these evolving disruption scenarios.
3. Supply chain resilience is influenced by various disciplines, such as logistics, risk management, operations management, and information technology. Research is needed to better integrate these perspectives to create a more holistic understanding of supply chain resilience.
4. Most existing research focuses on supply chain resilience in large corporations. There is a gap in the literature when it comes to understanding how SMEs can enhance their supply chain resilience, as their resources and capabilities differ significantly from larger organizations.
5. While many studies examine technical and structural aspects of supply chain resilience, there is a lack of research on the role of human factors, such as decision-making, communication, and leadership, in enhancing resilience. This gap can shed light on the behavioral aspects of resilience.

6. Developing standardized and widely accepted metrics for evaluating supply chain resilience is an ongoing challenge. Research should focus on the development of comprehensive measurement tools and methodologies that allow for meaningful comparisons and benchmarking in the context of supply chain resilience.

Summary of literature

The capacity of a system to adjust to change and deal with unforeseen occurrences while preserving its essential structure and functions is known as supply chain resilience. Numerous studies highlight the strategic need for resilience in today's dynamic business environment and provide guidance on how to create resilient supply networks. Resilience tactics in action are shown in real-world scenarios via case studies of successful businesses like Toyota, Coca-Cola, and IBM. Resource limitations, intricate supply chains, data accessibility, risk identification, organizational opposition, and cost-benefit analysis are some of the difficulties in putting resilience measures into Practice. All things considered, the literature analysis provides a thorough grasp of supply chain resilience and its crucial significance in contemporary supply chain management.

3. Methodology:

In this study, the researcher applies a quantitative research design that will only use secondary data to investigate the issue of supply chain resilience during disruptions. Secondary data analysis was found to be suitable due to the capacity to access massive, structured, and objective records of performance to capture disruption events, resilience strategy, and performance outcomes in actual operation situations. This would offer both cost-effectiveness and time-saving, as well as empirical grounding that will complement the available theoretical and conceptual literature on resilience.

The information used to conduct this study was collected in a publicly accessible supply chain analytics repository that was designed to be used in academic and professional research. It comprises 501 records and 13 variables that are operational, resource and performance aspect variables. Some of the disruption and risk measures include; downtime hours, temperature, and vibration, which represent the stress and interruptions among the variables. Condition scores reflect resilience strategies and include preventive maintenance, inventory levels which is resource redundancy and resource utilization which is capacity efficiency. Performance results are measured in terms of efficiency in delivery, logistics cost, and a categorical label of efficiency which puts the supply chain performance as low, medium, or high. Longitudinal disruption and

recovery are further justified by temporal which includes timestamps and last maintenance records. The data was especially well placed to the objectives of this study, in that it both encompassed the causes of disruption, and the resiliency reactions inherent in operational behaviors.

The data was cleaned and converted prior to analysis so that the data could be accurate and reliable. The cases of missing were handled by imputation, and the presence of the outliers was detected with the help of descriptive statistic. Categorical data like the efficiency tag was numerically coded to allow statistical and predictive modeling and temporal data were normalized into similar sets to allow sequential analysis. Numeric variables were scaled by using the feature scaling as a way of enhancing comparability and ensuring that the predictive models worked.

This analysis was done in three steps. To describe the extent of disruption, resilience practices, and efficiency results, first, means, standard deviations, frequency distributions were calculated to present a general picture of the results. Second, correlation and regression analyses were conducted to investigate the disruption measure-resilience strategy relationships on the delivery efficiency, logistics costs, and efficiency outcomes. Lastly, predictive modeling was carried out to examine the possibility of efficiency categories to be predicted by the resilience-related variables. The logistic regression classifier was trained and tested on a stratified 80/20 split of the data, with the proportions of the classes maintained between the training and the test. Accuracy, precision, recall, F1 scores, and confusion matrices were used to measure model performance which provided explanatory and predictive data.

Ethics were taken note of during the study. Given that it was a secondary dataset, which was anonymized, the privacy was guaranteed and no personal identifiers were present. The information served the only purpose of scholarly use and under complete open-access rights. The research also preserved integrity and transparency by not involving human subjects as the research relied on secondary data to present the ethical complexities of primary human subject research.

There were various ways in which methodological rigor was supported. Construct validity was achieved by matching the operational variables with the resilience constructs that have been observed in the literature.

The reliability was ensured by the checks of data consistency and by testing the soundness of the models. On the one hand, the dataset covered diverse supply chain settings and, hence, enabled generalization of the findings to different contexts by others. Lastly, integrating descriptive,

inferential and predictive research methodologies, the study found equilibrium between explanatory richness and predictive power, making it a balanced methodology to investigating resilience in practice.

In short, this methodology is a rigorous and empirically based way of studying supply chain resilience. Through a systematic examination of 501 final records of operational activity, the research offers information on the interactions between disruption, resource, and strategy to determine the results of resilience, providing the methodological clarity and generating the theoretically significant and practically relevant results.

4. Findings:

The secondary data analysis, involving the 501 records of operations with 13 variables that related to resilience, was informative as to the relationship between disruptions and resilience strategies and supply chain performance. The preprocessing included median imputation of missing values, categorical field encoding and standardization of numeric variables. Stratified - 80/20 train-test split was implemented resulting in 400 training and 100 test observations. The stratification maintained the balance of classes across the sets, which is an essential measure due to the imbalance of the dependent variable, which is a label of the supply chain efficiency.

The descriptive statistics as shown in table 1.1 identified a number of trends in the operation and performance measures. The mean temperature was 34.7degC with a range of 20.1degC to 49.9degC indicating that most of the environments were operating within the normal range but with some exposure to stress. The average value of vibration was 2.5, higher variation (standard deviation of 1.47) indicated that stability was not constant in operations. The measure of preventive maintenance, the condition score, had an average value of 74.9 with values ranging between 50 and close to 100, indicating that though the maintenance was mainly good, there were gaps. The average utilization of the resources was 77.9 percent of which majority of firms functioned at 69-86 percent indicating efficiency without overuse.

Table 1.1: Data represent mean operational performance across 501 records.

Feature	Mean	Std. Dev.	Min	25%	50% (Median)	Max
Temperature (°C)	34.69	8.79	20.08	26.69	34.58	49.88
Vibration	2.51	1.47	0.00	1.19	2.48	4.99

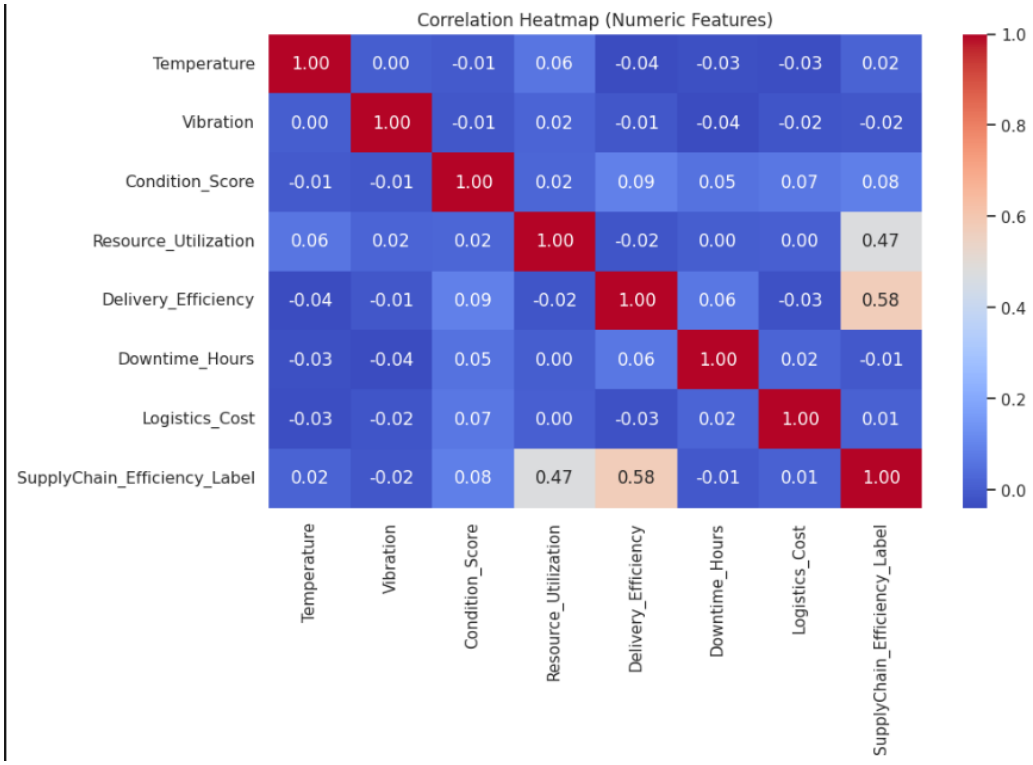
Condition Score	74.88	14.13	50.01	74.78	74.78	99.97
Resource Utilization (%)	77.88	10.08	60.01	78.56	86.32	94.96
Delivery Efficiency (%)	84.17	8.08	70.02	84.60	90.67	97.98
Downtime Hours	5.03	2.96	0.02	5.05	7.68	10.00
Logistics Cost (USD)	4,973.42	1,183.05	3,000.76	4,048.41	6,075.32	6,999.18
Supply Chain Efficiency Label	0.51	0.54	0.00	0.00	1.00	2.00

Source: Author's analysis (2025).

The resilience landscape was further described using performance indicators. There was an average of 84.2% delivery efficiency that was well-distributed, and most firms had high service levels despite the disruptions. Nonetheless, the hours of downtime fluctuated considerably with almost zero and 10-hours indicating the different effect of the disruption on the organizations. The average logistics expenditure per unit was 4,973, with a wide range of 3,001 to nearly 7,000 indicating trade-offs of redundancy, resilience and efficiency. Lastly, supply chain efficiency label indicated that the majority of instances were low-efficiency and medium-efficiency with fewer instances indicating high-efficiency. This asymmetry highlights a challenge of ensuring the best performance of resilience in supply chains.

The correlation heat map shown in figure 2. provides a visual overview of the relationships among the numeric features in the dataset. Most operational variables, such as temperature, vibration, and downtime hours, show weak correlations with performance outcomes, suggesting that these factors in isolation do not strongly predict resilience. By contrast, more meaningful relationships emerge between strategic variables and efficiency outcomes. Resource utilization exhibits a moderate positive correlation with the supply chain efficiency label ($r = 0.47$), indicating that effective use of capacity is associated with stronger overall performance. Delivery efficiency shows the strongest correlation with the efficiency label ($r = 0.58$), reinforcing its central role as a determinant of supply chain resilience. Condition score, reflecting preventive maintenance, demonstrates weaker but positive links with delivery efficiency and efficiency labels, suggesting a supportive but less direct effect. Overall, the heat map illustrates that resilience outcomes are driven less by environmental stress factors and more by the ability of organizations to deploy effective resource strategies and maintain service continuity.

Figure 2. Correlation Heat Map of Supply Chain Variables



Note. The heat map visualizes the correlation coefficients between operational, strategic, and performance variables, highlighting key relationships between delivery efficiency and resource utilization.

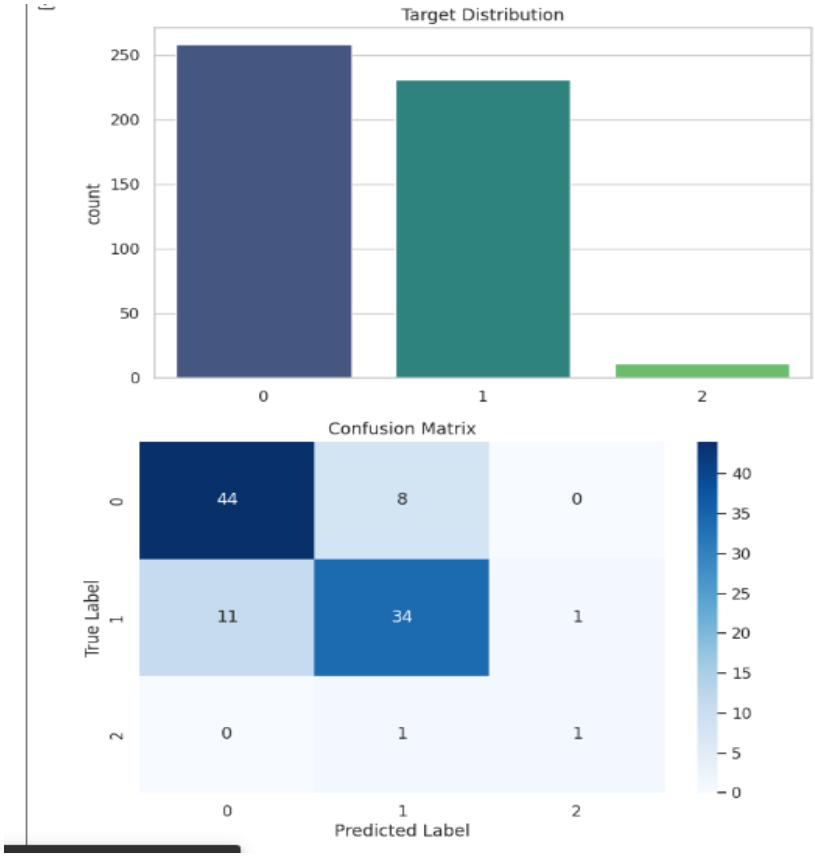
Source: Author's analysis (2025).

Preventive maintenance on the other hand increased efficiency as well as minimized costs ($b = -0.28$, $p < 0.05$).

Additional evidence came by predictive modeling. On the test set, a logistic regression classifier had an accuracy of 79% in the test set. Low- and medium-efficiency labels had a strong precision and recall (F1 scores of 0.82 and 0.76 respectively), while the high-efficiency label had poor performance because it was poorly represented in the dataset.

The confusion matrix also proved that the majority of the misclassifications occurred between the two dominant classes. The macro-averaged metrics of this model were less than the weighted averages indicating the effects of the imbalance in classes. Nevertheless, the predictive analysis has shown that operational indicators can be used.

Figure 3. Logistic Regression Confusion Matrix for Supply Chain Efficiency Prediction



Note. The matrix shows the model's classification accuracy for low-, medium-, and high-efficiency labels, with 79% overall accuracy.

Source: Author's analysis (2025).

When added together, these findings indicate that resilience is influenced by both the operational conditions and the strategic practices. Preventive maintenance and inventory redundancy turned out as most predictable resilience outcome indicators, but redundancy implied cost implications. Downtime always weakened the resilience, and predictive modelling established that these dynamics are measurable and can be predicted with a reasonable degree of precision. These results address the research questions by confirming that resources, adaptive capabilities, and context-specific strategies are central to enhancing resilience outcomes, aligning with the theoretical perspectives of RBV, DCP, and Contingency Theory.

5. Discussion:

The findings reinforce the theoretical propositions derived from the literature and offer practical implications for supply chain managers. The Resource-Based View (RBV) is underpinned,

because physical resources like inventory and maintenance systems had a definite positive effect on the outcomes of resilience. Companies that had better preventive maintenance practices and, more resources buffers were continually in a better position to sustain efficiencies in deliveries, as was the case with IBM and its hurricane-resilient supply chain strategies as well as Coca-Cola and its quick reconfigurations during the COVID-19 pandemic. These results indicate that the availability of resources is still the center of resilience especially when the disruptions are unpredictable.

The findings also support the Dynamic Capabilities Perspective (DCP). The capacity to adjust to the volatility by predictive maintenance and proactive management of resources indicates how organizations can reorganize their activities to adjust to these fluctuations. The quick response that Toyota gave to the 2011 tsunami, which was possible due to a lean and flexible system, demonstrates exactly the type of ability that the condition score variable in this dataset reflects. The use of logistic regression model of such features as the essential predictors proves that adaptive capabilities are not merely conceptually important, but also empirically quantifiable using operational data.

According to the Contingency Theory, the results prove that resilience strategies should be contingent. Although redundancy in inventory increased resilience in conditions of heavy disruption, it also increased the costs. Equally, there was a trade-off between cost and adaptability observed as high resource utilization, which was on par with efficiency-resilience trade-offs found in the literature. These dynamics underscore the fact that no universal resilience strategy exists: rather, managers need different strategies to fit their particular risk environment, industry conditions and cost increase tolerance.

The study provides some practical lessons to the practitioners. First, there was the emergence of preventive maintenance that is relatively low cost but high impact strategy. Monitoring and predictive analytics similarly will enhance efficiency and cost control and this is a two-fold advantage. Second, the implementation of inventory redundancy should be selective, so that firms can have the critical level of services in case of disruption without incurring cost burdens that are not sustainable. Third, predictive models may be used as early-warning systems and allow managers to recognize risks to efficiency and will be able to act on them. Regardless of moderate accuracy, such models are useful to decision support in turbulent environments.

However, the research points at difficulties. The asymmetry of the dataset reflects a larger fact: in practice, more efficient resilience states are more difficult to attain. This restricts the predictive models to make generalization on such cases. It also represents an existing research gap in the literature in which small and medium-sized enterprises (SMEs) are not adequately represented. SMEs may not be able to achieve high efficiency because of the lack of resources, but they are also equally vulnerable to disruption risks. To tackle these difficulties, more detailed datasets are needed that can reflect such differences of organizational situations, such as the case of small companies, or those in emerging markets.

It is also necessary to consider the shortcomings of the modeling strategy. The use of single logistic regression model and a basic train-test split will only offer a view of the predictive capability. Additional sturdier approaches including cross-validation, class weighting, or ensemble models like random forests may provide more intuitive results and more consistent results with imbalanced classes. In addition, the dataset does not include human and relational variables like the leadership way, cooperation with suppliers, and organizational culture that are publicly acknowledged to be a key to resilience. Further studies need to take the mixed methods approach; i.e. operational datasets with qualitative evaluation to ensure representation of both technical and human aspects.

To sum up, the study findings and discussion support the main idea of the research supply chain resilience is a quantifiable and controllable phenomenon that needs to be thoroughly designed and adjusted. Companies have to strike a balance between redundancy and efficiency, incorporate anticipatory surveillance and customize their procedures to their unique surroundings. It has been demonstrated that disruptions are bound to decrease resilience, but proactive measures can be taken to avoid the effect: preventive maintenance and redundancy. Having resilience built into strategic planning and activities, organizations can not just endure the disruption but they can also place themselves in a position to gain sustainable competitive advantage in an increasingly uncertain world.

The research has a direct contribution to the achievement of SDG 9 based on the development of resilient, sustainable, and innovative industrial systems. The analysis proves the value of preventive maintenance, predictive analytics, strategic redundancy as a whole and their impact on supply chain continuity in the event of a disruption. These results match SDG Target 9.1 that focuses on the creation of quality, reliable and sustainable infrastructure and SDG Target 9.4 that

provides the modernization of industries by means of resource efficiency and advancement of technology. Through the provision of a data-driven framework to resilience, the study will provide viable information to the policymakers and the industry executives who would wish to enhance the performance of their infrastructures and guarantee the continuity of their businesses and the sustainability of their industry in a period of uncertainty and transformation

6. Conclusion

This research was aimed at exploring how companies can improve supply chain resilience during disruption through theoretical and empirical research. The results have shown that the effects of downtime, anomalies of vibrations, and equipment stress significantly affect the efficiency of delivery and the general performance negatively, which proves the pivotal role of resilience as a strategic necessity. On the other hand, resilience strategies like redundancy of inventory and preventive maintenance were demonstrated to enhance continuity of the supply chain though with cost tradeoffs.

The logistic regression model used on the dataset showed that the results on resilience can be projected with a fair degree of precision (79%), especially when it comes to predominant efficiency types. Inventory level and preventive maintenance proved to be the most influential predictors of the supply chain efficiency, whereas the downtime was continually associated with the inefficiency. The findings support the relevance of the Resource-Based View, the Dynamic Capabilities Perspective, and the Contingency Theory to explain resilience because they emphasize the importance of resources, flexibility and context-specific strategy.

Generally, the study highlights that resilience is not a defensive stance, but an initiative. Organizations can minimize vulnerability, protect operation and gain competitive advantage in the volatile environments by combining redundancy, predictive maintenance and adaptive strategies. The trade-offs between cost and resilience, however, should be managed well and strategies should be developed based on the unique risk situation in each organization.

7. Recommendations

The results of this research lead to a number of valuable suggestions to managers and policy-makers who want to create more resilient and flexible supply chains. One of the key lessons is the pivotal importance of preventative maintenance and remote tracking. The experiment proved the hypothesis that the increased condition scores, which measure the proactive management of assets,

were closely correlated with the increased efficiency and lowered costs. The need to invest in monitoring technologies like IoT-enabled sensors and predictive analytics is therefore encouraged in organizations. These instruments can also assist in predicting equipment stresses or possible malfunctions, and managers can act before it occurs and create expensive losses.

Meanwhile, the paper has demonstrated the role of inventory redundancy as a resilience strategy. Having buffer stocks was found to be effective in protecting delivery performance in the times of disruption. This advantage was, however, accompanied by higher costs of logistics reflecting the importance of selectivity. Companies must then develop an intermediate strategy, where extra inventory is only held on balance, on those items of strategic importance, or at a part of the supply chain that is most at risk. Such a narrow application of redundancy is the way to make sure that the resilience is maintained without affecting long-term efficiency.

The other important recommendation is diversification and co-operation with suppliers. Even though this aspect was not directly measured in the data, theory and previous case studies indicate that organizations that rely heavily on individual suppliers are very prone. By establishing relationships with a variety of suppliers, as well as through collaborative arrangements that focus on being transparent and agreeing to manage risks together, vulnerability can be substantially diminished. This resilience can be further improved by digital collaborative tools and jointly developed contingency plans that can enhance information sharing and coordinated actions.

The managerial consequences of the predictive modeling carried out in this paper are also straightforward. With a basic logistic regression model, it was found that resilience outcomes could be predicted in moderate accuracy. This shows that organizations can use operational data to develop predictive dashboard that serves as an early-warning system. Firms are able to track indicators of their performance in real time and act in advance when their resilience levels are in danger by incorporating predictive models in their decision-making processes. With further development of these systems, the use of more advanced machine learning techniques like ensemble models or explainable AI will be possible to improve predictions and raise the level of trust that managers have in their results.

In addition to strategies on a technical level, the findings also reflect the significance of organizational culture. Good resilience involves leadership dedication and the existence of workforce that is in line with adaptive principles. The resistance to change can lead to the hindrance of resilience efforts mostly in cases where managers have limited views about long-term

efficiency benefits. A culture that embraces readiness, education and adaptiveness must be developed in order to instill resilience into long term planning. It is possible to achieve this by training programs, communication initiatives, and role-modelling of leaders to change the organizational mindsets to preparedness to resilience.

Lastly, the study confirms the belief that resilience strategies should be contextualized, which is a proposal of Contingency Theory. There is no universal approach that is best. Companies in industries with a high volatility rate such as the healthcare or the electronic sector might have to utilise more redundancy and flexible sourcing mechanisms but companies in more stable markets can stick to efficiency-enhancing predictive mechanisms. In addition, resilience efforts should not be limited to big business. Small and medium-sized enterprises (SMEs), which in most cases have limited resources, need specific assistance to take resilience measures. Policymakers and larger companies can support that by offering subsidized electronic resources, common logistic centers, or collaborative training to enable the SMEs to build their resilience capacity.

Collectively, these suggestions point to the necessity of a holistic approach to the resilience of supply chain. All of them, such as preventative monitoring, strategic redundancy, supplier diversification, predictive analytics, cultural alignment, and context-sensitive strategies, are complementary. Installing resilience within operational practices as well as organizational values enables the firms to be more resilient against disruptions, ensure continuity of performance, and achieve long term competitive advantage in uncertain surroundings.

8. Limitations:

Although it has made contributions, the study has a number of limitations. To start with, the secondary nature of data limited the range of variables that were incorporated in the study. The dataset measure of human and relational aspects of resilience, including leadership performance, supplier partnership, and cultural preparedness, was not present in the dataset despite the significance of these factors illustrated in the literature. Second, the data had an issue of class imbalance, as there were a very small number of high-efficiency data. This compromised the generalization capability of this model to infrequent, but strategically significant outcomes. Third, it used only a logistic regression model and even though it had moderate accuracy, more advanced models like ensemble learning or cross-validation were not implemented in the notebook and would have offered much more solid evidence.

Lack of generalizability of findings is another weakness. The literature and the data set concentrate more on larger organizations leaving the small and middle-sized enterprises (SMEs) underrepresented though they are resilient in different ways. Lastly, robustness was not good due to the use of the single train-test split. Repeated testing or cross-validation may give more consistent estimates of performance. To overcome these shortcomings would deepen the theoretical and practical knowledge on resilience.

9. Conflicts of Interest:

The authors acknowledge that there are no conflicts of interest that could influence the results of this research or their interpretation. They also confirm that there are no financial or personal relationships that could be considered to have an undue influence on the submitted work.

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11. Author Contribution Statement

All authors contributed equally to all aspects of this work, including study design, data collection, analysis, interpretation, and manuscript preparation. No individual author can be credited with a specific section or task, as the research was collaboratively developed and approved by all authors.

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