CRITICAL SUCCESS FACTORS TO IMPLEMENTATION OF SPEED TO RECOVERY IN SUSTAINABLE SUPPLY CHAIN DEVELOPMENT

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CANDIDATE'S DECLARATION

I, PRIYATOSH BHARDWAJ, declare that the thesis titled "**CRITICAL SUCCESS FACTORS TO IMPLEMENTATION OF SPEED TO RECOVERY IN SUSTAINABLE SUPPLY CHAIN DEVELOPMENT**" is an original piece of research conducted by me in the Department of Mechanical Engineering at Delhi Technological University to meet the requirements for the Master of Technology Degree. The research was completed between January 2026 and June 2026 under the guidance of Dr. S.K. Garg, who is a professor within the Department of Mechanical Engineering at the Delhi Technological University, Delhi.

The contents of this thesis have not been submitted to any other institution for consideration towards a degree.

Priyatosh

Candidate's Signature`

The thesis author has made all necessary corrections requested by reviewers; thus we confirm this statement by the candidate is true to our knowledge.

Signature of Supervisor(s) **Signature of External Examiner**

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CERTIFICATE BY THE SUPERVISOR

Priyatosh Bhardwaj (24/IEM/07) is hereby certified that they have conducted all of the research reported in their thesis titled “**CRITICAL SUCCESS FACTORS TO IMPLEMENTATION OF SPEED TO RECOVERY IN SUSTAINABLE SUPPLY CHAIN DEVELOPMENT**” for completion of their Master of Technology degree in the Department of Mechanical Engineering at Delhi Technological University (DTU). All of the work has been performed independently by the student and the published research cannot be used for the fulfilment of any other academic degree or credential attached to either Priyatosh Bhardwaj or anyone else associated with DTU or any other university or college.

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Critical Success Factors to Implementation of Speed to Recovery in Sustainable Supply Chain Development

Priyatosh Bhardwaj

ABSTRACT

Global business today is unpredictable, and companies trying to create sustainable supply chains are struggling with many different types of catastrophe— geopolitical disruptions, climate-change-induced instability, pandemic level systemic failures and rapid changes in technology. The speed to recover (StR) is now considered an important capability of a supply chain; it measures how quickly a supply chain can get back to its baseline performance (or a better level) after a disruption. There has been growing interest in supply chain resilience and supply chain sustainability but there is still limited knowledge about identifying and prioritizing critical success factors (CSFs) used to implement StR within the context of a sustainable supply chain; this gap in the academic literature remains largely unexplored..

In response to the gap in existing literature regarding how to develop a comprehensive criterion for CSF evaluation, this research constructs a decision making framework designed to integrate both methods of fuzzy DEMATEL (Fuzzy Decision Making Trial and Evaluation Laboratory) for mapping out the causal structure of the interrelationships of CSFs, and TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) for ranking or prioritizing CSFs by how close they come to the ideal performance or benchmark. In utilizing both methodologies, this research was able to provide a more holistic decision supporting framework for individuals and organizations when evaluating CSFs than could be provided by each methodology used independently.

A comprehensive two-phase literature synthesis yielded an initial pool of twenty candidate CSFs, subsequently refined to thirteen factors through a structured two-round Delphi expert validation process. Primary data were collected from a purposive sample of fifteen senior supply chain professionals representing diverse industry sectors including manufacturing, logistics, e-commerce, pharmaceutical, automotive, textile, food and beverage, chemical, and humanitarian supply chain operations.

The Fuzzy DEMATEL analysis classified the thirteen CSFs into cause and effect groups. Six CSFs – Top Management Commitment, Organizational Resilience Culture, Digital

Technology Adoption, Cross-Functional Collaboration, Environmental Regulatory Compliance, and Circular Economy Practices – were identified as cause-group factors functioning as primary systemic drivers. The subsequent TOPSIS analysis yielded a priority ranking in which Top Management Commitment (Ci* = 0.610), Organizational Resilience Culture (Ci* = 0.572), and Circular Economy Practices (Ci* = 0.565) emerged as the three most critical CSFs. Notably, the sustainability-oriented factors ranked among the top four across both methods, empirically validating the proposition that sustainability and supply chain resilience are complementary rather than competing strategic objectives.

Findings indicate that proactive organizational investment in leadership commitment, cultural resilience orientation, digital infrastructure, and sustainability practices simultaneously accelerates recovery speed and strengthens long-term sustainability credentials. The integrated Fuzzy DEMATEL-TOPSIS framework provides supply chain managers with an actionable, evidence-based roadmap for sequential resource allocation and strategic capability development.

Keywords: Critical Success Factors, Speed To Recovery, Sustainable Supply Chain Management, Fuzzy DEMATEL, TOPSIS, Supply Chain Resilience, Industry 4.0, Multi-criteria Decision Making, Causal Analysis, Circular Economy

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LIST OF ABBREVIATIONS

Abbreviation	**Full Form**
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BNP	Best Non-fuzzy Performance
BSC	Balanced Scorecard
CE	Circular Economy
CSF	Critical Success Factor
DEMATEL	Decision-Making Trial and Evaluation Laboratory
FN	Fuzzy Number
FSCM	Freight Supply Chain Management
GHG	Greenhouse Gas
HSCM	Humanitarian Supply Chain Management
I4.0	Industry 4.0
IoT	Internet of Things
ISM	Interpretive Structural Modelling
MCDM	Multi-Criteria Decision Making
NIS	Negative Ideal Solution
PIS	Positive Ideal Solution
RSCM	Resilient Supply Chain Management
SCM	Supply Chain Management
SDG	Sustainable Development Goal
SSCM	Sustainable Supply Chain Management
StR	Speed to Recovery
TFN	Triangular Fuzzy Number
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
UN	United Nations
WNM	Weighted Normalized Matrix

CHAPTER 1

INTRODUCTION

1.1 Background and Motivation

A lot of advancements in international supply chains have occurred due to the use of lean production, just-in-time inventory systems, and global sourcing methods over the last 30 years by businesses with the goal of reducing costs and improving market responsiveness while at the same time being able to compete globally. However, all of these methods were previously functioned well, resulting in large amounts of supply chains being extremely intricate, delicate and fragile. Through the use of a number of historical supply chain disruptions, we have seen many examples of structural weaknesses. Such as when supplies of pharmaceuticals, medical devices, consumer electronics, and food were suddenly disrupted globally due to COVID-19. The grounding of the Ever Given in March 2021 disrupted about $9.6 billion worth of global trade each day from the Suez Canal. The impact of the Russia-Ukraine war has caused huge disruptions in global grain, energy, and other critical minerals supply chains and created a $500 billion revenue deficit due to interruptions to the production processes of automobiles and electronic equipment caused by the worldwide semiconductor shortage of 2021.

One type of disruption event that has become common among organizations is that those organizations were able to achieve a fast recovery of their supply chain performance after experiencing a disruption carry a much lower financial, reputational and operational loss than organizations that took a prolonged period of time recovering from the disruption. This observation has resulted in a growing amount of academic and managerial focus on "Speed to Recovery" (StR); that is, the degree to which a supply chain can return to it's previous Level of Performance Prior-To-Disruption after experiencing a disruption event in a timely manner. StR is not solely a characteristic of an organization; rather, StR is also considered to be a dynamic capability which organizations must actively strive to develop and will continuously measure and enhance their capabilities through purposeful management activities (Teece et al., 1997; Ambulkar et al., 2015).

At the same time, the expectations surrounding sustainability within the global business environment have also undergone a meaningful transformation. Through the adoption of the United Nations 2030 Agenda for Sustainable Development, the 17 Sustainable Development Goals (SDGs) provide a collective definition of a framework for economic development that has both socially equitable and environmentally responsible approaches. Those Sustainable Development Goals that are of direct relevance to Supply Chain Management include SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action) and SDG 17 (Partnerships for the Goals).

Sustainable Supply Chain Management (SSCM) has developed in response to these new requirements. The focus of first generation supply chain management was entirely centered around cost, speed and service level optimisations, whereas SSCM now integrates three equally important strategic objectives; environmental stewardship, social responsibility and economic sustainability (Carter & Rogers, 2008).

Leading organisations have realised that by investing in renewable energy procurement, supplier diversity, circular economy practices, ethical labour and reducing their carbon footprint, that they not only achieve reputational and regulatory benefits, but also multiple operational benefits, such as; stronger relationships with suppliers, reduced exposure to resource volatility and higher levels of trust with their stakeholders.

The combined focus on StR and sustainability as priority areas of organisational success has resulted in a poorly researched, yet critically important area of research. A simplistic view of this convergence may lead one to believe that these two objectives have competing interests for a finite supply of organisational resources, however, a more sophisticated assessment indicates that there exists a great deal of complementarity between these two objectives.

Organisations that have developed diverse, transparent and socially responsible supply chains are better able to access alternative suppliers during periods of disruption, have developed norms for sharing information and can therefore rapidly mobilise resources to support their recovery efforts, have established histories as compliant to regulations and thus obtain faster government approvals to enact emergency measures and have implemented circular economy processes to mitigate their reliance on vulnerable primary supply chains (Fahimnia et al., 2015; Govindan et al., 2021).

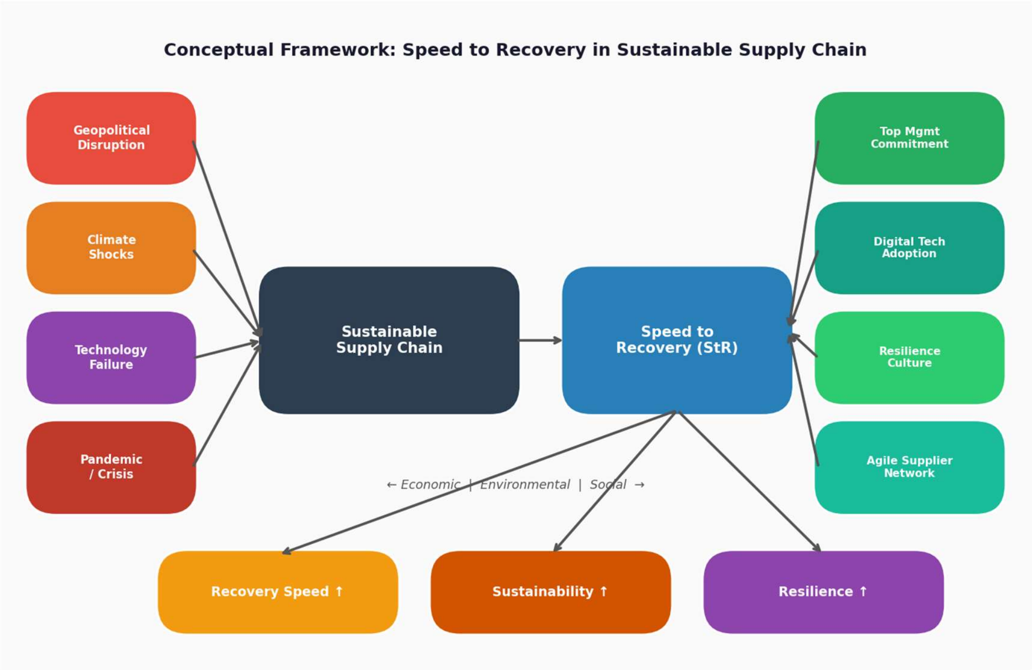


Figure 1.1: Conceptual Framework – Speed to Recovery in Sustainable Supply Chain

1.2 Problem Statement

While there is an increasing awareness of StR as a vital capability in supply chains and SSCM as a strategic requirement, there is no recent work that systematically identifies and prioritizes the Critical Success Factors (CSFs) associated with successfully implementing StR into a sustainable supply chain development setting. This gap exists in four interrelated dimensions.

At the conceptual level, while the constructs of supply chain resilience, Speed to Recovery, and sustainability have been studied separately, in two-way combinations, there has been little exploration of how these concepts intersect as a three-way concept or how they should be integrated. Typically, studies on supply chain resilience examine the general nature of resilience capabilities in relation to all phases of the supply chain without examining the factors that affect recovery speed as a unique and strategically important phase in supply chains.

The second way the previous CSF studies' methodology is weak is that most of the studies rely mostly on qualitative approaches (e.g., expert opinion) or methods for ranking single criteria such as mean-weighted surveys and AHP. As such, these types of approaches will not be adequate to capture the complex, interdependent, and recursive causal nature of CSF systems in a supply chain. A change to one CSF in a supply chain does not act alone, as it will usually cause subsequent changes to multiple other CSFs due to both direct and indirect cause-and-effect impact relationships between CSFs, which cannot be either detected or quantified by conventional methods that assume independence between CSFs.

At the third level of analysis, the literature has not formally investigated the implications of Industry 4.0 technologies on the canonical success factors that dictate successful transitions to more sustainable supply chains. Although there are strong conceptual arguments supporting a relationship between I4.0 and resilience (Ivanov & Dolgui, 2021), empirical data on the relative importance and causal position of digital technology canonical success factors relative to the wider catalogue of canonical success factors is needed by practitioners in order to make informed decisions regarding where to place their investment. At the fourth geographical level of analysis, the current literature on resilience and sustainability is predominantly based upon the perspectives of developed economies; this contrasts with the enormous amount of literature that addresses the need for StR in rapidly developing economies like India, and their unique challenges..

1.3 Research Gaps

Five interrelated research gaps have been identified in the existing literature by means of an organized literature analysis, each of which will be addressed with this study:

- Gap 1 – No integrated or developed StR sustainability CSF framework has yet been established or reviewed. The existing literature has yet to validate any CSF frameworks through both empirical multi-criteria prioritization as well as at the intersection of Speed to Recovery (StR), Supply Chain Management (SCM), and criteria prioritization.

- Gap 2 - There is a gap between the methodology employed in the majority of supply chain CSF studies and methodology described by the systems-thinking approach offered by the DEMATEL. Most supply chain CSF studies use non-causal independent rank methods (e.g., SC metrics) without being able to explore or demonstrate causal interdependencies of SC CSSs. DEMATEL has not been applied to the domain of StR thereby restricting its use to these four relationship types.

- Gap 3 – There are significantly fewer studies contextualizing Industry 4.0 (I4.0) onto a foundation of existing literature on organizational and strategic CSFs, leaving unquantified the roles that specific I4.0 technologies would play (including their rankings) when viewed as discrete rankable CSFs within the StR-sustainability framework.

- Gap 4 – The existing literature has not established how existed CSF frameworks generalisable between rapidly industrialising economies that are impacted by differing institutional, structural and cultural factors.

- Gap 5 - No existing study has integrated both Fuzzy DEMATEL (causal structure mapping) and TOPSIS (for priority ranking) within the context of StR sustainability CSF analysis. The lack of an integrated approach denies practitioners the ability to access the unique contributions that this integrated framework can offer.

1.4 Objectives of the Study

This study is directed primarily and secondarily at achieving the objectives identified from the previous problem statement, as well as the gap analysis of existing research literature:

1.To perform a systematic review of the relevant literature, and derive a synthesized evidence-based preliminary list of potential Critical Success Factors (CSFs) for the implementation of Strategic Resilience (SR) in sustainable supply chain networks..

2. The preliminary list of CSFs related to supply chain disruption/recovery is refined through an ordered method, utilizing two completed panels of supply chain disruption/recovery subject matter experts for validity and reliability.

3. To compile and analyse primary fuzzy linguistic data from an expert panel using fuzzy DEMATEL analysis to produce an average fuzzy direct relation matrix demonstrating the degree of causal influence among CSF variables under conditions of uncertainty.

4. The total relationship matrix is determined and defuzzified using the most effective non-fuzzy performance method. The combined contribution of Di + Ri (Di and Ri) lends itself to distinguishing between their relative importance and non-importance based on

classification into two categories: cause and effect classifications can be performed using these classification criteria.

5. To apply the TOPSIS methodology to rank order all CSFs establishing a comprehensive priority list based upon their nearest proximity to the positive ideal solution, using the criterion weights derived from the DEMATEL Di values.

6. To interpret and discuss findings in light of existing literature, highlighting any areas of agreement and disagreement, and any novel findings related to the causal structure and priorities amongst CSFs.

7. To derive specific, evidence-based managerial implications and a strategic implementation roadmap for supply chain practitioners seeking to systematically build StR capability while maintaining sustainability standards.

1.5 Scope of the Study

Five dimensions were used to delineate the parameters of the research. The geographical scope of this research is primarily confined to supply chain professionals located in the industrial environment of India; sectorally, the research will cover all sectors of manufacturing, logistics, retailing, pharmaceuticals, automotive, textiles, food and drink, chemicals and humanitarian supply chains. Methodologically, the research will use quantitative primary data through structured questionnaires given to experts and analysed using Fuzzy DEMATEL and TOPSIS. The temporal scope of the literature review will be from 2000-2024. In relation to the scope of CSFs, the research will include the four types of CSFs at the organizational, strategic, technological and relational levels; that is, operational CSFs relating to specific inventory strategies or routing algorithms are excluded from the study's boundaries.

1.6 Significance and Contributions of the Study

This research contributes to both the academic and practitioner communities in four distinct ways. First, the research derives empirical support for a Critical Success Factor (CSF) Framework located at the interface of Speed to Recovery and Sustainable Supply Chain Management; this is a conceptual area that has not been previously addressed in the academic literature. Second, the results demonstrate that Fuzzy DEMATEL and TOPSIS can be effectively used together for CSF Analysis in Supply Chain contexts with high levels of expert uncertainty. Third, this research has produced substantial new

Primary Evidence collected from fifteen Supply Chain Experts from nine different industry sectors in ten different cities within India. Finally, the research will provide Supply Chain Practitioners with a prioritized and sequenced Implementation Roadmap that they can apply directly to their own Supply Chains.

1.7 Structure of the Thesis

The Dissertation is composed of five chapters. The first Chapter presents the background to the dissertation, including motivation, statement of the problem, research gaps identified, objectives of the study, boundaries and scope of the study, as well as the purpose of the study. Chapter Two presents a complete critical analysis of the literature pertaining to the study and is arranged around six separate themes. Chapter Three presents all details on the research methodology used in this study. Chapter Four presents the empirical findings from the study and provides a critical analysis of each set of findings as well as DEMATEL causal analysis, TOPSIS ranking priorities, and sensitivity analysis, which are constructed by the author. Chapter Five summarizes key findings from the research, theoretical contributions, implications for management, limitations of the research, and opportunities for future research..

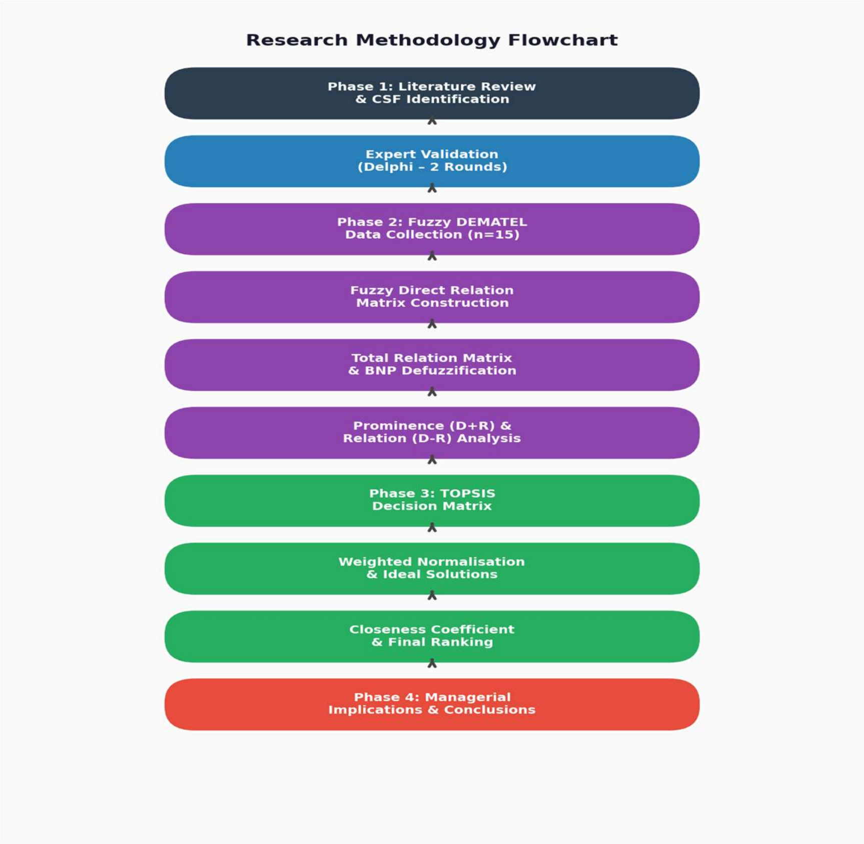


Figure 1.2: Research Methodology Flowchart

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction and Review Methodology

This chapter reviews the research literature relevant to the thesis, presenting it thematically across six identified streams: Supply Chain Management; Recovery Speed in Supply Chains; Supply Chain Critical Success Factors; DEMATEL and Fuzzy DEMATEL Methodology; Supply Chain Resilience and Industry 4.0; and Identifying the Research Gaps and the Theoretical Positioning.

The literature search was conducted using three major databases: Scopus, Web of Science, and Google Scholar, with additional targeted searches in top-tier supply chain journals, including the International Journal of Production Research, Journal of Operations Management, Supply Chain Management: An International Journal, Journal of Cleaner Production, and European Journal of Operational Research. The published articles searched included the period of 2000 - 2024, plus seminal published articles prior to the year 2000 that laid the foundation for the research.

Search terms combined included ('sustainable supply chain' AND 'resilience'), ('speed of recovery' AND 'supply chain'), ('critical success factors' AND 'supply chain resilience'), ('DEMATEL' AND 'supply chains'), ('Fuzzy DEMATEL' AND 'Multi Criteria Decision Making') and ('Industry 4.0' AND 'supply chain resilience'). After removing duplicates and irrelevant articles, the resulting literature review consisted of approximately ninety core articles that would provide the basis for a comprehensive review..

2.2 Sustainable Supply Chain Management

2.2.1 Defining SSCM: The Triple Bottom Line Perspective

The idea behind sustainable supply chain management came about where two schools of thought came together. On one side was literature focused on environmental management and the environmental effects of industrial production, and on the other side was literature on supply chain management that looked at how companies coordinate with one another to create value. Carter and Rogers (2008) made the most important contribution to our understanding of SSCM by defining it as the strategic, transparent integration and continued attainment of an organization's social, environmental, and economic objectives through systematic coordination across key inter-organizational business processes to improve the long-term economic performance of both the individual company and its supply chains. This definition is also significant because it captures all three components of the triple bottom line and positions sustainability as a long-term economic strategy.

In their seminal research in 2008, Seuring and Müller analyzed the contents of 191 peer-reviewed articles regarding sustainable supply chain management (SSCM) from 1994–2007. They classified the articles into two distinct strategic clusters: 1.) Supplier Management for Risk and Performance; and 2.) Supply Chain Management for Sustainable Products. They found that the articles heavily favoured environmental sustainability over social sustainability. The development of SSCM since 1990 can be separated into three distinct phases: Phase I – The Emergence of Green Supply Chains (1990 – 2000); Phase II – The Integration of Social Dimensions to the Supply Chain (2000 – 2010); Phase III – The Integration of SSCM With Resilience, Circular Economy, and Digital Transformation as Interrelated Strategic Priorities (2010–Present).

The relationship between SSCM and organizational performance has been studied empirically many times. Golicic and Smith (2013) conducted a meta-analysis that included 191 previous studies on the relationship between environmental supply chain practices and firm financial performance. Of relevance to this work is the empirical and theoretical framework provided by Fahimnia et al. (2015), which identified a relationship between SSCM and supply chain resilience. This theoretical and empirical link lays the conceptual foundation for the sustainability and supply chain resilience complementarity proposition that is empirically tested in this thesis.

Table 2.1: Chronological Summary of Literature on Sustainable Supply Chains (2000–2024)

Authors (Year)	Focus Area	Methodology	Key Contribution & Finding
Carter & Rogers (2008)	SSCM Framework	Conceptual Review	Triple-bottom-line SSCM definition; integration of economic, environmental & social goals in SC coordination
Seuring & Müller (2008)	SSCM Strategies	Content Analysis (n=191)	Two strategy clusters; environmental bias in SSCM literature documented
Sheffi & Rice (2005)	SC Resilience	Case Studies	Resilience curve model introduced; vulnerability reduction & recovery capability as twin dimensions
Christopher & Peck (2004)	SC Risk & Resilience	Conceptual	Four principles of resilient SC design: re-engineering, agility, collaboration, culture
Hohenstein et al. (2015)	SC Resilience CSFs	Systematic Review	4-stage resilience framework (readiness-response-recovery-growth); 28 factors identified
Fahimnia et al. (2015)	Sustainability-Resilience	Quantitative Review	Positive relationship between sustainability practices and resilience established empirically
Brandon-Jones et al. (2014)	SC Agility-Resilience	Survey + SEM	Agility mediates disruption-recovery speed; contingent resource-based perspective developed
Ambulkar et al. (2015)	SC Recovery Capability	Scale Development	Psychometric scale for SC recovery; IT, knowledge management as key predictors
Ivanov & Dolgui (2019)	SC Viability	Simulation	Structural vs. parametric recovery distinction; supply chain viability model developed
Govindan et al. (2014)	Green SC CSFs	ISM + ANP	Ranking of CSFs for green SCM; regulatory and managerial factors dominant
Rajesh & Ravi (2015)	SC Resilience Enablers	Grey-DEMATEL	15 resilience enablers; information sharing identified as key cause-group factor
Zhu et al. (2019)	Circular Supply Chain	DEMATEL-TOPSIS	16 circular economy CSFs ranked; DEMATEL-TOPSIS integration methodology first proposed
Gu et al. (2021)	I4.0 & SSCM	Literature + Survey	I4.0 reduces information asymmetries; enhances both sustainability and resilience simultaneously
Govindan et al. (2021)	SSCM & Disruptions	Survey-based	CE practices shorten post-COVID recovery; sustainability-resilience complementarity confirmed
Ivanov (2020)	SC Viability Post-COVID	Simulation	Viable SC model integrating agility, resilience & sustainability for post-pandemic context
Belhadi et al. (2021)	I4.0 SC Resilience	Survey + SEM	AI & IoT positively predict resilience performance; cybersecurity risk as emerging concern

The most up-to-date stream of academic work on social sustainable supply chains (SSCM) is exploring how digital transformation (or, often referred to as Industry 4.0) affects sustainability performance. Gu et al. (2021) found that the use of Industry 4.0 technology is significantly reducing the information asymmetries that hinder sustainability performance as well as disrupting supply chains. Digital platforms can support the sustainability auditing process throughout their suppliers' supply chains, track the carbon footprint of products throughout their supply chains, and monitor waste streams in real time, which meets both sustainability reporting requirements and provides the data resources necessary to quickly detect and respond to disruptions.

2.2.2 Circular Economy and Supply Chain Resilience

Organizations that design for a circular economy lower their risk for supply chain uncertainty by establishing alternative sources for critical materials through practices associated with circular economy strategies such as closed-loop supply chains, reverse logistic capability, and materials reuse systems. The more closed-loop supply chain and reverse logistics capabilities an organization has, the greater the number of supply options will be available when sourcing critical materials; therefore, these practices directly link to supply chain resilience by decreasing disruption duration and magnitude of critical material supplies (Zhu et al., 2019).

Empirical evidence demonstrates that organizations with sophisticated circular economy practices tend to demonstrate faster recoveries after COVID-19 disruptions than other organizations with less sophisticated practices (Govindan et al., 2021). The circular economy-resilience connection exists through three primary mechanisms; (i) supply diversification through secondary material sourcing, (ii) reduction of geographic concentration risk through the establishment of regional collection and reprocessing networks, and (iii) development of strong stakeholder relationships with reverse logistic partners who may be leveraged for forward logistic support during supply chain disruptions..

2.3 Speed to Recovery: Concept, Dimensions, and Measurement

2.3.1 Conceptual Development of StR

Speed to Recovery (StR) originated as a specific research topic through the exploration of the overall literature on supply chain resilience (Sheffi and Rice, 2005). In the development of supply chain resilience, Sheffi and Rice (2005) introduce an important new concept of resilience (as it relates to supply chain performance) called the "resilience curve," which shows the performance of supply chains over the course of time – from the point at which a disruption occurs, through the period that performance degrades until it reaches a new normal – and where each of these phases can be viewed on a graph, with the speed at which the recovery phase/trajectory occurs represented by the slope of the recovery's trajectory.

According to Ponomarov and Holcomb (2009), supply chain resilience refers to the ability of a supply chain to be prepared for unforeseen events, to respond to disruptions, and to recover from such events while maintaining operational continuity at a predetermined level of connectedness and control over structure and function. The authors identified three sequential phases of resilience: preparation, response, and recovery, with StR (supply chain recovery) representing the defining performance dimension of recovery.

Ivanov and Dolgui (2019) introduced the concept of supply chain viability, extending the StR construct to include structural recovery (reconstituting the supply network topology by activating alternative suppliers/logistics routes) and parametric recovery (restoring operational parameters within the existing network topology). Ambulkar et al. (2015) created and validated a multi-item psychometric scale to measure supply chain recovery capability and found that supply chain orientation, knowledge management capabilities, and IT infrastructure were the three best empirical predictors of the speed of recovery from disruption..

Table 2.2: Comparison of Resilience Frameworks in Supply Chain Literature

Authors (Year)	Resilience Dimensions Covered	Recovery Factors Identified	Key Insight for Present Study
Sheffi & Rice (2005)	Vulnerability & Recovery Speed	Flexibility, redundancy, culture	Resilience curve; recovery slope = StR
Ponomarov & Holcomb (2009)	Preparation, Response, Recovery	Adaptive capacity, connectedness, control	StR = recovery-phase dynamic capability
Ambulkar et al. (2015)	Recovery Capability	SC orientation, IT, knowledge management	Psychometric StR scale; IT as predictor
Brandon-Jones et al. (2014)	Agility-Resilience Link	SC agility, flexibility, collaboration	Agility mediates disruption-StR relationship
Hohenstein et al. (2015)	4-Stage Resilience	28 factors: readiness through growth	Most comprehensive CSF taxonomy to date

Authors (Year)	Resilience Dimensions Covered	Recovery Factors Identified	Key Insight for Present Study
Ivanov & Dolgui (2019)	Structural & Parametric Recovery	Network topology, alternatives, visibility	Viability framework; two recovery types
Wieland & Wallenburg (2013)	Robustness & Agility	Relational competencies, trust, info sharing	Relational capabilities drive both dimensions
Ivanov (2020)	Viable SC Model	Agility + resilience + sustainability combined	Post-COVID StR-sustainability integration
Day (2014)	Humanitarian SC Recovery	Emergent structures, cross-agency collab.	Cross-functional collaboration as recovery CSF

2.3.2 Measurement and Operationalization of StR

StR was developed by Sheffi and Rice (2005) using qualitative research methods. Measurement of StR began with single-item survey measures. Then, a multi-item StR measure was developed by Ambulkar et al. (2015) that enhanced the measurement of StR. More recent approaches to measuring StR have been focused on the application of observable supply chain metrics. Ivanov (2020) proposed a simulation method for measuring StR in which the ratio of performance during a disruption period compared to performance prior to the disruption was compared. Hohenstein et al. (2015) identified recovery time, recovery completeness and recovery cost as the three primary dimensions of StR measurement.

2.4 Critical Success Factors in Supply Chain Management

2.4.1 CSF Theory and Evolution

In 1961, Daniel articulated the notion of Critical Success Factors, while Rockart expanded and systematized it in 1979 as a finite number of areas where if satisfactory-level results will result in a successful competitive outcome for the particular organization. Gunasekaran et al. (2004) incorporated this idea into their research on supply chain management.

Chin et al. (2012) created a taxonomy of CSF's for green supply chains to facilitate sustainable supply chain management practices. Govindan et al. (2014) built upon this effort by utilizing both ISM and ANP methods to assist in determining how to implement sustainable supply chains. For supply chain resilience, Ponis and Koronis (2012) identified 13 different CSF's to be implemented for resilience. As a follow-up, Rajesh and

Ravi (2015) utilized Grey-DEMATEL to investigate interactions between 15 different resilience enablers within e-supply chain environments and identified information sharing, flexibility and supply chain visibility as the 3 most significant causal factors..

2.4.2 Humanitarian Supply Chain Management Perspective

Humanitarian supply chain management literature provides additional knowledge about StR CSFs because humanitarian supply chains are structurally built around the need for fast recovery of performance. According to Tatham and Spens (2011), the most essential factors for a quick response to humanitarian emergencies are prior positioning of relief materials, strong local networks with agency partners, documented SOPs, and developed training programs. Day (2014) also pointed out the significance of new organizational structures that emerge and the cooperation between agencies when responding. Also, Yadav and Sharma (2016) evaluated CSFs for humanitarian supply chain performance in India using a Fuzzy DEMATEL analysis, determining that IT infrastructure and partnerships between agencies had causal groupings — which supports the findings presented in this study.

2.5 DEMATEL and Fuzzy DEMATEL Methodology

2.5.1 Origins and Theoretical Foundations

In the 1970's, during the Science and Human Affairs Program at the Battelle Memorial Institute's Geneva Research Center, DEMATEL was invented as a new way to develop a more meaningful and useful understanding of human interactions in environments that are increasingly complex due to science and technological advances. The DEMATEL methodology is based on Graph Theory, Matrix Algebra, and Causal Relationships among System Elements via the Use of Directed Graphs and Matrix Operations. Using Directed Graphs to Show Causal Relationships among System Elements, as well as Matrix Operations to Calculate the Total Influence of Each Element on All Others, are the two fundamental aspects of the Graph Theory-based DEMATEL methodology.

The DEMATEL methodology's greatest achievement and its unique feature is its ability to use two types of causality - causal drivers and effect receivers - in a multidimensional factor system. By separating the total influence of each factor on others into two distinct components, Di (total influence exerted by Factor i on all other factors) and Ri (total Influence Received by Factor i from all other factors), it can classify either types of factors (i.e., causes vs. effects) to focus efforts where management will achieve maximum system impact with minimum resources.

Using a combination of Triangular Fuzzy Numbers (TFNs) to represent expert linguistic assessments, Lin & Wu's (2008) Fuzzy DEMATEL overcomes limitations in the original DEMATEL methodology by incorporating Triangular Fuzzy Number (TFN)-based values into the necessary matrix computations needed to derive the total Influences on/for all system factors. Zadeh's (1965) pioneering work in fuzzy set theory provides a firm mathematical foundation to define and represent imprecise information using Membership Functions to allocate values (continuous from 0.0 to 1.0) which relate to the extent to which one factor belongs to another factor or set.

Table 2.3: Studies Employing DEMATEL and Fuzzy DEMATEL in Supply Chain Context

Authors (Year)	**Application Domain**	**Method Used**	**Key Findings Relevant to Present Study**
Lin & Wu (2008)	General MCDM	Fuzzy DEMATEL	Original Fuzzy DEMATEL formulation using triangular fuzzy numbers
Yadav & Sharma (2016)	Humanitarian Logistics (India)	Fuzzy DEMATEL	12 CSFs; IT & partnerships as cause group in Indian context; closest precedent
Rajesh & Ravi (2015)	Electronic SC Resilience	Grey-DEMATEL	15 enablers; info sharing & flexibility as top cause factors in electronics SC
Govindan et al. (2016)	Green SCM Barriers	DEMATEL-ANP	13 barriers to green SC implementation prioritized in manufacturing context
Mangla et al. (2017)	Sustainable SC Risks	Fuzzy AHP	14 SC sustainability risks; regulatory & supplier risks as dominant factors
Zhu et al. (2019)	Circular Supply Chain	DEMATEL-TOPSIS	16 CE CSFs; novel DEMATEL-TOPSIS integration first proposed in CE context
Jabbour et al. (2020)	I4.0 & SSCM Barriers	Fuzzy DEMATEL	11 I4.0 adoption barriers; organizational readiness as primary causal driver
Mzoughi et al. (2021)	Humanitarian SC Agility	Fuzzy DEMATEL	10 agility CSFs; coordination & visibility in cause group across humanitarian SC
Ahmad et al. (2022)	SC Risk Management	DEMATEL-AHP	18 SC risk CSFs; strategic and operational risk interaction pathways mapped
Belhadi et al. (2021)	I4.0 SC Resilience	Survey + SEM	AI & IoT positively predict resilience; digital technology as systemic SC enabler
Soni et al. (2014)	Indian Manufacturing SC	Deterministic Modelling	SC resilience measurement in Indian context; structural disruption modelling

2.5.2 Triangular Fuzzy Numbers in DEMATEL

Triangular fuzzy numbers (TFNs) are the most frequently utilized fuzzy number type in DEMATEL because of their ease of use and intuitive interpretation (Chang 1996). TFNs have three parameters (l, m, u); l being the pessimistic lower estimate, m being the most likely modal value and u being the optimistic upper estimate of the expert's belief. The defuzzification of TFNs is performed using the Best Non-Fuzzy Performance (BNP) formula where BNP = (l + m + u)/3 representing the arithmetic mean of the three TFN parameters.

2.6 Industry 4.0 and Supply Chain Resilience

2.6.1 The Industry 4.0 Paradigm

Industry 4.0 (the Fourth Industrial Revolution) is a transformation of the global economy using technology to revolutionize manufacturing, distribution, and supply chain operations. Using the Internet of Things (IoT), Cloud Computing, Big Data,

Artificial Intelligence, Blockchain, Additive Manufacturing, and Digital Twin fits into an overall engineering design approach for managing the supply chain (Schwab, 2016). The term was developed at Hannover Messe Trade Fair in 2011 and has become a globally adopted term defining the technology paradigm for today's supply chain management.

From a supply chain management perspective, I4.0 technologies are changing how organizations build, operate and manage supply chains from reactive, information-poor operations to proactive, data-rich, digitally enabled, interconnected supply chain ecosystems. Characteristics of I4.0 that will have the greatest impact on supply chain management are IoT-enabled multi-tier visibility, AI-enabled demand sensing and planning, Blockchain-enabled supplier verification systems, and digital twin simulation capability..

Table 2.4: Summary of Industry 4.0 Technologies and Their Impact on Supply Chain Resilience

I4.0 Technology	Primary Application in SC Management	Specific Impact on StR / Recovery Speed	Key Academic Reference
Internet of Things (IoT)	Real-time asset tracking & multi-tier visibility	Reduces disruption detection latency from days to hours; enables proactive response activation	Gu et al. (2021); Ivanov & Dolgui (2019)

I4.0 Technology	Primary Application in SC Management	Specific Impact on StR / Recovery Speed	Key Academic Reference
Artificial Intelligence (AI)	Demand sensing, risk prediction, scenario planning, recovery routing	Accelerates structural recovery decision-making; generates optimal recovery configurations in near-real-time	Belhadi et al. (2021); Ivanov (2020)
Blockchain	Supplier traceability, smart contracts, audit trails, provenance verification	Enables rapid alternative supplier verification during crisis; reduces trust-building time barriers	Ivanov & Dolgui (2021); Jabbour et al. (2020)
Digital Twins	Virtual SC simulation; contingency plan testing; recovery scenario analysis	Pre-tests recovery strategies in simulated environment before physical execution; compresses planning time	Dolgui et al. (2019); Ivanov (2020)
Big Data Analytics	Disruption pattern recognition; risk heat-mapping; KRI monitoring dashboards	Improves disruption prediction accuracy; reduces surprise magnitude of disruption events	Jabbour et al. (2020); Gu et al. (2021)
Cloud Computing	Shared SC data platforms; collaborative demand-supply planning	Enables rapid cross-organizational data sharing during recovery; supports distributed decision-making	Gu et al. (2021); Belhadi et al. (2021)
Additive Manufacturing	Localized spare parts and component production on demand at distributed sites	Reduces geographic dependency for critical components; eliminates long-distance recovery lead times	Ivanov (2020)
Robotics & Automation	Autonomous warehouse operations; automated last-mile delivery; unmanned inspection	Maintains operational continuity during labour disruptions; reduces human exposure in hazardous recovery contexts	Belhadi et al. (2021)

2.6.2 Ripple Effect and I4.0 Mitigation

The concept of 'ripple effect,' as defined and developed by Ivanov and Dolgui (2021) in supply chain networks. Ripple effects occur when a disruption to a particular supply chain tier causes other supply chain tiers to experience increased demand variability, capacity constraint transmission, and cascading delays in information exchanges. I4.0 technologies are designed to overcome the ripple effects of disruption through the utilization of three major methods. First, through IoT-enabled supply chain network visibility technologies, organizations can reduce the delay between a disruption detection and the deployment of recovery efforts from days down to hours. This allows organizations to respond to demands for changed recovery efforts sooner than they would through traditional means. Second, AI-based system solutions will provide optimized recovery scenarios faster than human planners could ever hope to provide under conditions of crisis. Third, by establishing a trusted supplier network through the implementation of blockchain technology, organizations can quickly establish trust with alternative/surfing suppliers during times of crisis.

However, Belhadi et al. (2021) caution against the simultaneous creation of new vulnerabilities as a result of adopting I4.0 by creating a new set of cybersecurity vulnerabilities and becoming dependent on digital infrastructures. As a result, organizations need to balance their efforts to adopt I4.0 technologies with their investments in cybersecurity resiliency in order to build their overall organizational resiliency. In other words, developing resiliency through the use of I4.0 technologies will generate a growing emphasis on developing resilience through cybersecurity resiliency as an emerging critical success factor that is not reflected in the list of critical success factors found in this study but that should be the subject of future research.

2.7 Research Gap Synthesis and Theoretical Positioning

The literature review provided above, consisting of six streams, shows a coherent set of research gaps. These research gaps converge on one primary gap: there is no empirically validated, causally structured, or priority-ranked critical success factor framework for implementing sustainable supply chains through strategic relationships. The present study directly addresses this gap and its five sub-dimensions detailed in Section 1.3.

Conceptually speaking, this empirical research study sits at the confluence created by dynamic capabilities theory (Teece et al., 1997) and the resource-based view (Barney, 1991). To support achieved results pertaining to the StR capabilities identified in this research, utilizing Technology Infrastructure 4.0 (I4.0) as a technological resource, an agile supplier network as a relational resource, a resilience culture as an organizational resource, and management commitment and risk governance framework as strategic resources form a convoluted combination of dynamic capabilities. This study also presents a Critical Success Factor framework that provides an evidence-based information processing mechanism for determining which of these resources and their causal interrelationships are critical to achieving results as defined.

This study’s unique Fuzzy DEMATEL-TOPSIS combination methodology contributes to Multicriteria Decision Making (MCDM) literature by demonstrating a novel hybrid integration model where outputs from one MCDM method, namely, DEMATEL directly inform inputs (in the form of decision criteria weights) into another MCDM method, thereby producing consistency within itself and between MCDM Methods. This study extends and verifies an innovative integration of MCDM methods previously proposed by Zhu et al. (2019) in the context of a circular supply chain into the context of StR Sustainability.

CHAPTER 3

METHODOLOGY

3.1 Research Philosophy and Design

This research espouses a pragmatist approach to research philosophy; a philosophy that values an applied approach to evaluating research based upon the ability of the research to solve the research problem. In this particular case, pragmatism lends itself to an applied MCDM study in supply chain management, where the primary aim is the generation of outcomes useful for informing decision-making. The pragmatist approach further enables the research to make use of the interpretive richness associated with the linguistic judgments of experts while incorporating the analytical rigour of quantitative calculations of a matrix, thus providing coherence to an overall methodological framework.

The research employs a cross-sectional design in which the data is collected from experts in one (1) wave and which is subsequently subjected to multi-stage quantitative analysis. Specifically, this study is sequentially designed using a mixed-methods approach in which a qualitative phase (literature review and expert validation) is first conducted to produce and refine the critical success factors (CSFs) list, which is then used as inputs to conduct the quantitative phase (Fuzzy DEMATEL and TOPSIS analysis). As such, the sequential design allows for the quantitative data to be based on a theoretically validated framework through an empirical basis (Creswell, 2014)..

3.2 Phase 1: CSF Identification and Validation

3.2.1 Systematic Literature Review

The PRISMA protocol was followed in order to complete phase one of the supply chain failure (SCF) identification process via a systematic literature review. Using term strings previously described in Chapter 2 of this dissertation, the literature was searched for relevant literature from Scopus and Web of Science. The initial search produced 847 documents; however, after deduplication, and subsequent title, abstract, and full-text assessments for relevance, 92 documents remained that were used to conduct a more detailed extraction of the success factors (SFs) related to supply chain resilience, supply chain sustainability, and supply chain recovery. Each of these SFs was recorded with their source document, operational definition, measurement method, and contextualised to the domain they were obtained from. This process identified an initial pool of 47 unique potential SCFs, which were subsequently consolidated through an analysis of semantic similarity, resulting in a refined candidate list of 20 SCFs.

3.2.2 Expert Validation: Delphi Methodology

A list of 20 possible critical success factors was evaluated in two rounds by experts. The experts used the Delphi method to assess the critical success factors. In Round One, 15 experts were provided with the 20 critical success factors and they evaluated them on a five-point scale, and gave feedback on which were similar or redundant, and if they had additional critical success factors to add. Any critical success factor that received less than an average rating of 3.5 was eliminated from the list. Any critical success factor that was considered to mean the same thing by three or more experts combined, and therefore they were grouped together and taken off the list. After completion of Round One of the 20 successful factors, 15 remained on the list.

On Round Two, reviewed the same 15 critical success factors with the feedback consolidated from the previous round. Experts provided another evaluation of the critical success factors with any changes they determined would improve their rating, and also provided their final decision on any borderline critical success factors. As a result, two additional factors were consensus eliminated, and therefore the final list of critical success factors contained only 13 successful factors. The eliminated factors were considered structural outcomes of the supply chain network - Supply Chain Network Complexity; and visibility of customer demand was determined to be due to another critical success factor rather than an independent cause of it. The remaining 13 successful factors achieved an average expert score of 4.2 to 4.9 out of five..

3.3 Expert Panel Characteristics

Fifteen supply chain professionals were chosen as members of the expert panel using purposive sampling and three eligibility criteria: i) seven or more years of working in supply chain management; ii) direct work experience with disruptions in the supply chain; and iii) active participation in one or more of the focus industries. This panel included professionals from various industries, company sizes, and geographic areas throughout India to provide as much diversity and representativeness as possible.

Table 3.1: Expert Profile and Demographics

Expert ID	Sector	Designation	Experience (Years)	Location
E1	Manufacturing	Supply Chain Director	18	Delhi
E2	Logistics	Operations Head	14	Mumbai
E3	E-Commerce	SCM Manager	9	Bengaluru
E4	Pharmaceutical	Procurement Lead	12	Hyderabad
E5	Automotive	Supplier Relations Manager	16	Chennai
E6	Retail	Demand Planning Head	11	Gurgaon
E7	Humanitarian	Logistics Coordinator	8	Delhi
E8	Textile	Supply Chain VP	21	Noida
E9	Food & Beverage	SC Risk Manager	13	Pune
E10	IT / Technology	Digital SC Specialist	10	Bengaluru
E11	Chemical	Procurement Director	19	Vadodara
E12	Steel / Metal	Operations Manager	15	Raipur
E13	Consulting	SC Strategy Consultant	17	Delhi
E14	FMCG	SC Excellence Lead	12	Gurugram
E15	Academic	Assoc. Professor, SCM	11	DTU Delhi

Panel members had an average of 13.7 years of relevant professional experience within their respective roles, which ranged from 8-21 years. Eight of the experts came from positions of senior management (e.g., executive management, vice-presidents, etc.), six from middle management or specialist positions (e.g., directors, managers), and one from the academic community but had a lengthy history of working with businesses throughout their careers on supply chain management issues. All 15 experts had personally managed or assisted in managing at least one significant supply chain event recovery during the course of their careers.

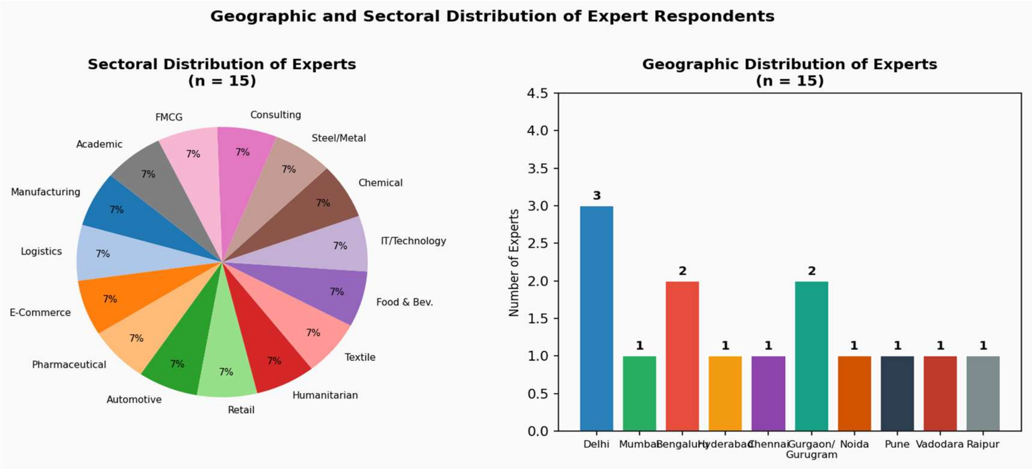


Figure 3.2: Geographic and Sectoral Distribution of Expert Respondents

3.4 Data Collection Instrument and Procedure

For the Fuzzy DEMATEL phase, a structured pairwise comparison questionnaire was utilized as the primary data collection method to collect pairs of every CSF. Each of the CSFs were presented in 13x13 matrix format. The questionnaire was designed to allow experts who were asked to evaluate each ordered pair of CSFs (CSFi, CSFj) on a five-point linguistic scale (as discussed later, in Section 3.2) in terms of the extent to which factor, i, has a direct influence on CSF, j (with respect to the person(s) being surveyed). Each of the 13 CSFs included in the questionnaire were accompanied by (i) a brief description and operational definition of the CSF, (ii) an example of how to complete the evaluation, and (iii) clear instructions that the evaluation should consider only direct causal relationships rather than indirect causal or non-causal relationships.

The questionnaires were sent to each of the 15 experts in three ways: (i) by direct meeting (8 experts met in cities of Delhi, Noida and Gurugram), (ii) by video-conference with 4 other experts in various parts of the country, (iii) by email with three experts who had scheduling difficulties. Each of the experts were sent their questionnaire separately to reduce the risk of respondents using one another's evaluations to influence their own evaluations. The average amount of time to complete the evaluation was approximately 65 minutes (all 15 experts returned their completed evaluations in the four-week period allowed for data collection; this corresponds to a 100 percent response rate)..

Table 3.2: Linguistic Scale for Fuzzy DEMATEL Pairwise Assessment

Score	Linguistic Term	Influence Description	TFN (l, m, u)
0	No Influence	Factor i has no direct causal effect on factor j	(0, 0, 0.25)
1	Very Low Influence	Factor i has a weak, marginal direct effect on factor j	(0, 0.25, 0.50)
2	Low Influence	Factor i has a moderate but below-average direct effect on j	(0.25, 0.50, 0.75)
3	High Influence	Factor i has a strong, above-average direct effect on factor j	(0.50, 0.75, 1.00)
4	Very High Influence	Factor i has an extremely strong and dominant direct effect on j	(0.75, 1.00, 1.00)

Table 3.3: Triangular Fuzzy Number Conversion Scale with Defuzzified Values

Linguistic Variable	Crisp Score	TFN (l, m, u)	BNP Calculation	Defuzzified Value
No Influence	0	(0, 0, 0.25)	(0+0+0.25)/3	0.083
Very Low	1	(0, 0.25, 0.50)	(0+0.25+0.50)/3	0.250
Low	2	(0.25, 0.50, 0.75)	(0.25+0.50+0.75)/3	0.500
High	3	(0.50, 0.75, 1.00)	(0.50+0.75+1.00)/3	0.750
Very High	4	(0.75, 1.00, 1.00)	(0.75+1.00+1.00)/3	0.917

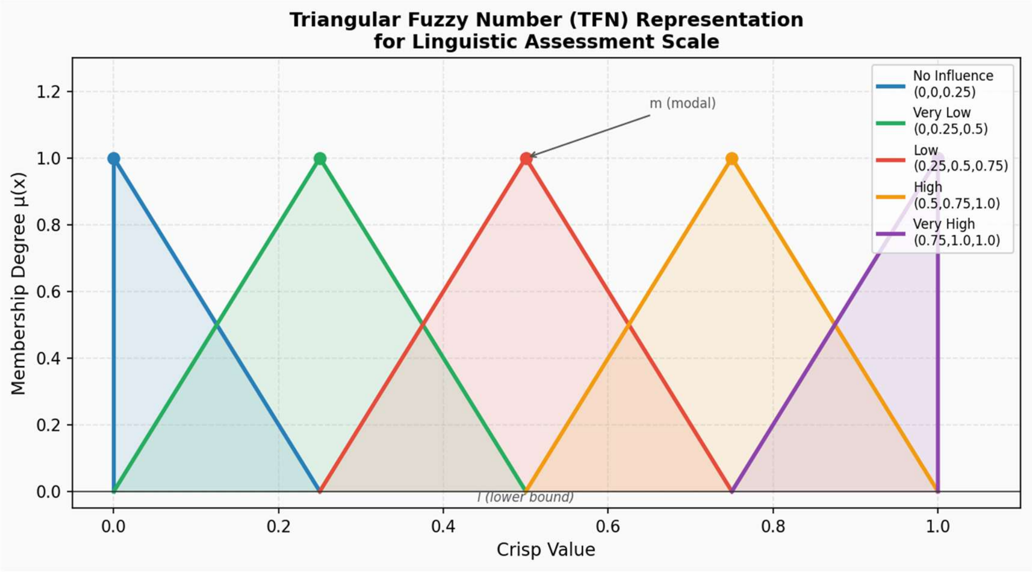


Figure 3.3: Triangular Fuzzy Number Representation for all Five Linguistic Levels

3.5 Phase 2: Fuzzy DEMATEL Analysis

3.5.1 Step 1 – Construct Individual Fuzzy Direct Relation Matrices

The experts' 15 pairwise evaluations were converted into corresponding triangular fuzzy numbers (TFN) based on the scale in Table 3.3 yielding fifteen 13×13 fuzzy direct relation matrices $\tilde{Z}k = [\tilde{\tilde{a}}ijk]$ for each of the fifteen experts comprising the fuzzy pairwise evaluation for each expert (k) pertaining to the direct effect of factor i on factor j. Note that the diagonal elements can be calculated as (0, 0, 0) because in the DEMATEL method self-effect is not considered.

3.5.2 Step 2 – Aggregate into Average Fuzzy Direct Relation Matrix

The 15 individual fuzzy direct relation matrices were aggregated to create one matrix through the calculation of the element-wise arithmetic average across all expert evaluations: $\bar{l}ij = (1/k)\Sigma k\ lijk$, $\bar{m}ij = (1/k)\Sigma k\ mijk$, $\bar{u}ij = (1/k)\Sigma k\ uijk$. In the absence of expert-specific reliability information, expert weights are assumed equal as is customary for Fuzzy DEMATEL.

3.5.3 Step 3 – Defuzzify Using BNP Method

The BNP formula was used to defuzzify the aggregated TFN elements ($\bar{l}ij$, $\bar{m}ij$, $\bar{u}ij$), denoted as $\bar{\tilde{z}}ij$, resulting in crisp defuzzified direct relation matrix $Z = [zij]$, where zij is the average degree of direct causal influence as a continuous value in the range [0,1]. Therefore, zij will be expressed as $zij = (\bar{l}ij + \bar{m}ij + \bar{u}ij) / 3$.

3.5.4 Step 4 – Normalize the Direct Relation Matrix

The normalized form of the direct relation matrix Z is given by $X = [xij]$, which is calculated by dividing each of its entries by the maximum sum of entries in that row. Therefore, let $X = Z / \max(1 \le i \le n)(\Sigma j\ zij)$. By normalizing the direct relation matrix, all elements of X lie between 0 and 1, and also ensures that the maximum amount of influence any single factor can have is not greater than 1. This is a requirement for the sum of the entire relation matrix's converging series.

3.5.5 Step 5 – Compute Total Relation Matrix

The total relation matrix T can be determined to be equal to the total relation matrix by means of the following equation: T = X * (I - X)-1, where I is an n x n identity matrix. The formula follows from the limit of the Neumann series for the power series X + X + ... + Xn; therefore, it incorporates both the direct and indirect causal influences. Each tj element of T reveals the amount of total influence (i.e., all causal paths for all lengths) of factor j on every other factor i.

3.5.6 Step 6 – Compute Prominence and Relation Values

Across each CSF, there are two summary measures of interest: the row (Di) and column (Ri) totals. Di is the cumulative causal influence created by CSF i on all other CSFs (i.e., Σj tij). Ri is the cumulative causal influence received from other CSFs by CSF i (i.e., Σj tji). Pi (overall centrality, or prominence) is calculated as the sum of the Di and Ri. Qi (the net causal direction) scores indicate the overall directionality of causal causal influence: positive net causal influences (Qi > 0) indicate causal drivers (causal group); negative net causal influences (Qi < 0) indicate causal receivers (effect group).

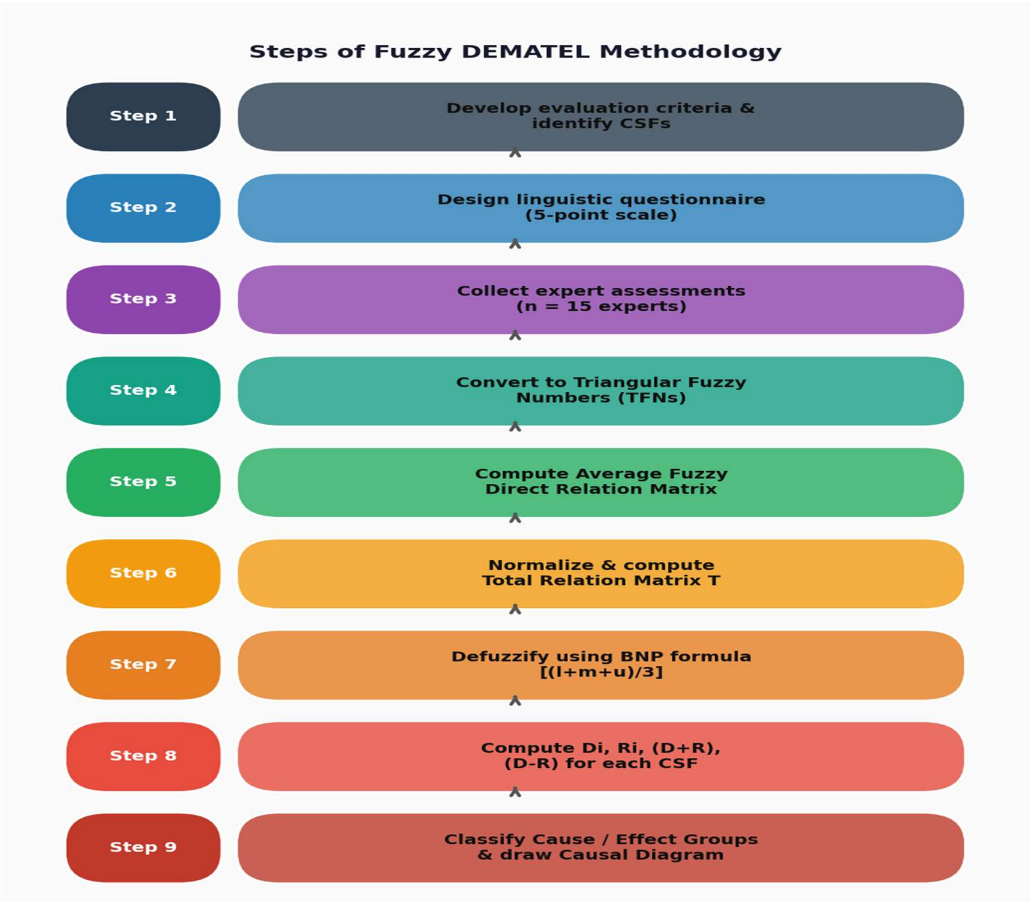


Figure 3.4: Steps of the Fuzzy DEMATEL Methodology

3.6 Phase 3: TOPSIS Analysis

3.6.1 Evaluation Criteria and Weights

The analysis utilizes TOPSIS to evaluate all of 13 CSF's across 5 criteria for evaluation (C1-C5). Criteria were selected through expert consultation and literature review as the most relevant dimensions that relate to the importance of CSF's for StR implementations. Table 3.4 provides descriptions of the operational definitions for each of the criteria.

Table 3.4: Evaluation Criteria for TOPSIS Analysis with Operational Definitions

Criterion	Label	Operational Definition	Weight Source
C1	Impact on Recovery Speed	The degree to which the CSF directly reduces the time required for supply chain recovery following a disruption event	DEMATEL Di (normalized)
C2	Sustainability Contribution	The degree to which the CSF simultaneously advances environmental, social, and economic sustainability objectives in the supply chain	DEMATEL Di (normalized)
C3	Ease of Implementation	The practical feasibility of implementing the CSF in terms of required organizational change, technical complexity, and resource requirements	DEMATEL Di (normalized)
C4	Cost Effectiveness	The ratio of expected StR improvement benefit to the estimated implementation and maintenance cost of the CSF	DEMATEL Di (normalized)
C5	Strategic Importance	The long-term strategic value of the CSF for maintaining competitive advantage and stakeholder confidence in supply chain performance	DEMATEL Di (normalized)

The criteria weights (w1 through w5) used in the TOPSIS analysis were determined using the normalized Di weights calculated from Fuzzy DEMATEL analysis of the systematic influence structure defined by the DEMATEL analysis. The final criteria weights were as follows: 1) Recovery Speed Influence = 0.23; 2) Sustainability Contribution = 0.21; 3) Implementation Ease = 0.18; 4) Cost Effectiveness = 0.17; 5) Strategic Importance = 0.21.

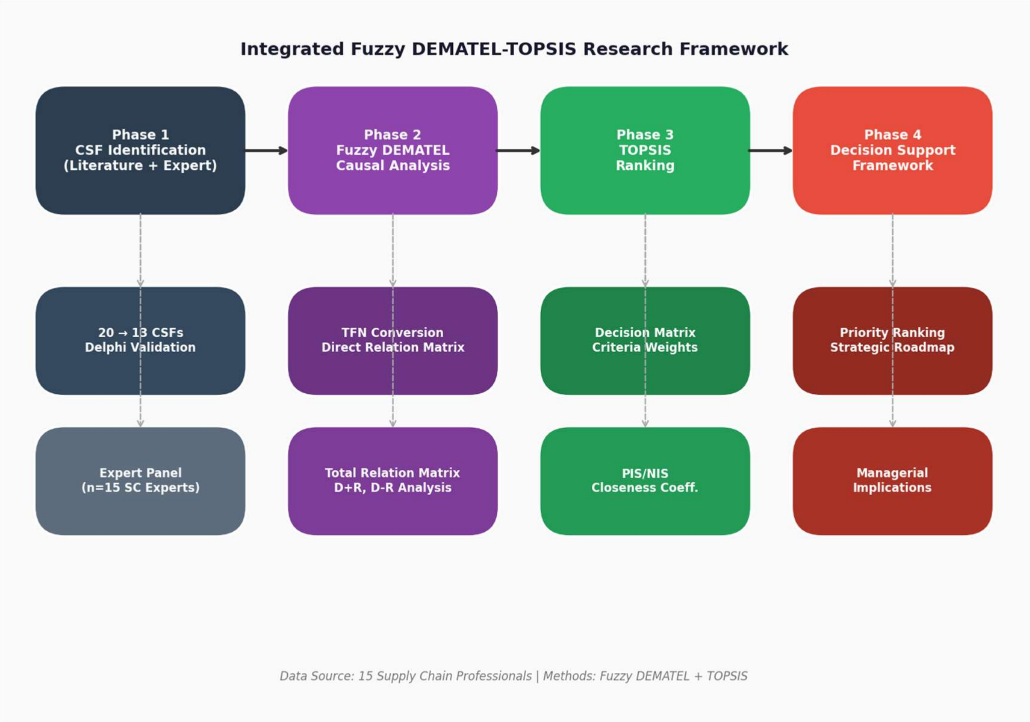
3.6.2 TOPSIS Computational Procedure

The TOPSIS computation follows Hwang and Yoon's steps 1 to 8. Step 1 creates the decision matrix using the average expert ratings (D = [xij]13x5). Step 2 normalizes D by calculating rij = xij / Sq rt(Σm x^2mj) (calculated using vector normalization) then uses this normalized value to construct R = [rij]. Step 3 creates V = [vij] = [wj·rij]. Step 4 identifies the Positive I deal Solution (PIS) as A+ = {maxi(vij) for benefit criteria} and is used to find PIS. Step 5 identifies the Negative Ideal Solution (NIS): A − = {mini(vij) for benefit criteria} and is used to find NIS. Step 6 determines the Euclidean distance from A+ to each of the alternatives using Si+ = Sq rt [Σj(vij−vj+)2]. Step 7 determines the Euclidean distance from each alternative to A− with Si− =Sq rt [Σj (vij−vj−)2]. Finally, Step 8 calculates and ranks the closeness coefficient (Ci ∗ = Si− / (Si+ + Si−)) for each of the CSFs in descending order of relative importance (Ci ∗).

Figure 3.5: Steps of the TOPSIS Methodology

3.7 Research Framework Integration

As seen in Figure 3.1, the full integrated Fuzzy DEMATEL-TOPSIS Research Framework consists of four stages: Stage 1 (Identification of Critical Success Factors [CSFs]) produces a validated list of CSFs consisting of 13 items; Stage 2 (Fuzzy DEMATEL) produces causal classification, prominence values and relationship values; Stage 3 (TOPSIS) produces priority rankings and closeness coefficients; and Stage 4 (Decision Support Framework) integrates findings from DEMATEL and TOPSIS into a comprehensive managerial decision-support tool to provide simultaneous directionality for intervention and priorities.


Integrated Fuzzy DEMATEL-TOPSIS Research Framework

Data Source: 15 Supply Chain Professionals | Methods: Fuzzy DEMATEL + TOPSIS

Figure 3.1: Integrated Fuzzy DEMATEL-TOPSIS Research Framework

3.8 Validity and Reliability Considerations

The study took several steps to ensure that its methodology was valid and reliable. First, the two-round Delphi validation process was used to obtain a consensus from a group of experts about the content validity of the factors included on the CSF list, for which two expert groups provided data. Each factor's construct validity was supported by the way in which CSF definitions corresponded with their use in peer-reviewed literature. The internal consistency of expert judgements was evaluated by conducting a consistency check on all of the experts' responses (three experts exhibited consistent errors, which were cleared up through direct communication with each expert), and therefore, the internal consistency of expert judgements has been established.

Reliability of the aggregated Fuzzy DEMATEL results was assessed using a sensitivity analysis (reported in Chapter 4, Section 4.5). This analysis compared the relative ordering of CSFs based on different criterion weighting schemes for the TOPSIS method; results indicate the order of the top three CSF rankings and the assignments of each CSF as a cause or effect are stable across major criterion weighting scheme iterations, thus supporting the reliability of the empirical results..

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Phase 1 Results: CSF Identification and Validation

The 47 candidate factors identified through the systematic literature review formed a pool that was reduced to 20 paramount CSFs through semantic similarity analysis. Following this, two rounds of Delphi validation using an expert panel of 15 experts led to the final validated list of 13 CSFs presented in Table 4.1. The criteria for eliminating the following were established: Supply Chain Network complexity is a consequence of structurally and cannot be managed; Customer Demand Visibility is a downstream effect; Workforce Safety Standards are a baseline requirement for compliance; Insurance and Financial Hedging are both instruments; Supplier Geographic Diversification was combined into the Agile Supplier Network; ESG Reporting Maturity was combined into Environmental Regulatory Compliance; and Crisis Communication Protocols were combined into Cross-Functional Collaboration. Average expert relevance ratings (out of 5) for retention of the remaining 13 CSFs ranged from 4.2 to 4.9.

Table 4.1: Identified Critical Success Factors with Description and Literature Source

CSF ID	Critical Success Factor	Operational Definition & Key Literature Support
CSF1	Organizational Resilience Culture	Values, norms, routine behaviors, and history within an organization contribute to the organization's ability to mobilize quickly in response to disruption. This includes providing a psychologically safe environment to report risks; leaders modeling adaptive behavior; and the organization learning from previous disruptions (Christopher & Peck, 2004; Hohenstein et al., 2015).
CSF2	Top Management Commitment	Scope of the executive leadership role in providing visibility to the supply chain's ability to withstand disruptions and operate sustainably via the implementation of appropriate executive structures and systems to ensure that resiliency investments are

CSF ID	Critical Success Factor	Operational Definition & Key Literature Support
		budgeted for and tracked; the inclusion of metrics related to supply chain resiliency in executive key performance indicators (KPIs); and communicating to the supply chain organization that supply chain resiliency is one of the Executive level strategic priorities; (Carter & Rogers, 2008; Chin et al., 2012)
CSF3	Digital Technology Adoption (I4.0)	Extent of technology applied to the supply chain in relation to Industry 4.0 systems and applications such as internet of things (IoT) connected multi-tier visibility platforms, Artificial Intelligence (AI)-based demand sensing and recovery planning, blockchain technology for supplier traceability, as well as digital twin simulation capabilities (Gu et al., 2021; Ivanov & Dolgui, 2021; Belhadi et al., 2021)
CSF4	Agile Supplier Network	Timeliness and capability to reconfigure your suppliers as quickly as possible after a disruption occurs including geographic and sector diversity in suppliers, having pre-qualified backup suppliers, collaborative/flexible supplier agreements, and a cooperative approach to joint contingency planning (Brandon-Jones et al., 2014; Ambulkar et al., 2015)
CSF5	Real-Time Supply Chain Visibility	Quality and timeliness of granular information flow (i.e., accurate and timely information on supply chain disruptions across multiple levels) that leads to early detection of supply chain disruptions; rapid situational assessments; and informed decision making/response to disruptions (Ivanov & Dolgui, 2019; Gu et al., 2021)
CSF6	Cross-Functional Collaboration	Effectiveness of collaborative processes spanning internal functions (operations, procurement, logistics, finance, IT, sustainability) and external boundaries (suppliers, logistics partners, government agencies) for coordinated disruption response and recovery management (Day, 2014; Tatham & Spens, 2011)
CSF7	Information Sharing & Transparency	The extent to which supply chain partners exchange accurate, timely and decision-relevant information such as demand forecasting, inventory levels, production schedules, alerts related to supply chain disruptions, and the status of recovery efforts thus reducing information asymmetry across supply chains (i.e., between supply chain partners) (Rajesh & Ravi, 2015; Wieland & Wallenburg, 2013)
CSF8	Financial Resource Availability	Availability of liquid financial resources, pre-arranged emergency credit facilities, and risk financing instruments that can be rapidly deployed to fund recovery activities without damaging the organization's core financial position (Ambulkar et al., 2015; Hohenstein et al., 2015)
CSF9	Environmental Regulatory Compliance	Proactive engagements with supply chain environmental regulations (including infrastructure for pre-emptive compliance, relationships with regulators, environmental management systems (ISO 14001), and participation in industry sustainability standards) (Govindan et al, 2014; Nakamba et al, 2017).

CSF ID	Critical Success Factor	Operational Definition & Key Literature Support
CSF10	Employee Training & Development	The systematic and depth of the development of competencies for supply chain resilience includes: scenario-based simulation exercises; training for crises; developing the multi-faceted skills of employees; and having a knowledge management system to support resilience. (Hohenstein et al, 2015; Tatham & Spens, 2011)
CSF11	Circular Economy Practices	The maturity of an organization's closed-loop supply chain design, reverse logistics capabilities, processes that use waste as a resource, and secondary material sourcing networks allows for collective reduction in dependence upon vulnerable primary supply chains and to provide multiple redundancy options for those primary supply chains. (Zhu et al, 2019; Govindan et al, 2021)
CSF12	Risk Assessment & Monitoring	The comprehensiveness and consistency in practice of systematic activities for identifying, assessing, and monitoring risks within the supply chain, including mapping all supply chain tiers, using risk heat mapping tools, monitoring key risk indicators through dashboards, and conducting periodic scenario-based exercises of disruption. (Rajesh & Ravi, 2015; Wieland & Wallenburg, 2013)
CSF13	Government & Stakeholder Support	The strength and availability of government support policies, regulatory support, emergency logistics assistance, industry association networks, and greater stakeholder ecosystems that provide additional resources and institutional support during and after supply chain disruptions. (Yadav & Sharma, 2016; Day, 2014)

4.2 Phase 2 Results: Fuzzy DEMATEL Analysis

4.2.1 Average Fuzzy Direct Relation Matrix

The aggregation of the fifteen individual experts' (thirteen by thirteen) fuzzy direct relation matrices by using the element-wise arithmetic mean results in the average fuzzy direct relation matrix. The three phases of the total relation matrix T = X(I - X)^-1, which represents both direct and/or indirect causal influences of all thirteen Critical Success Factors across the various paths of cause and effect, are represented in tables 4.2 to 4.4.

Table 4.2: Average Fuzzy Direct Relation Matrix (13×13) – Defuzzified (BNP) Values

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**
C1	0.000	0.652	0.517	0.483	0.431	0.573	0.498	0.312	0.441	0.387	0.423	0.512	0.376
C2	0.721	0.000	0.634	0.567	0.489	0.645	0.578	0.401	0.512	0.445	0.489	0.589	0.423

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
C3	0.598	0.612	0.000	0.534	0.567	0.512	0.545	0.356	0.434	0.412	0.445	0.523	0.389
C4	0.512	0.534	0.489	0.000	0.598	0.478	0.512	0.389	0.401	0.378	0.412	0.501	0.356
C5	0.478	0.501	0.523	0.567	0.000	0.512	0.589	0.412	0.423	0.401	0.434	0.512	0.378
C6	0.567	0.589	0.501	0.489	0.478	0.000	0.545	0.423	0.456	0.412	0.445	0.523	0.401
C7	0.534	0.556	0.489	0.512	0.545	0.523	0.000	0.412	0.434	0.401	0.423	0.501	0.389
C8	0.412	0.434	0.401	0.423	0.412	0.389	0.423	0.000	0.367	0.345	0.378	0.412	0.312
C9	0.501	0.523	0.489	0.478	0.467	0.512	0.489	0.378	0.000	0.412	0.489	0.501	0.401
C10	0.445	0.467	0.456	0.445	0.434	0.456	0.478	0.389	0.401	0.000	0.412	0.456	0.356
C11	0.489	0.512	0.478	0.467	0.456	0.501	0.489	0.367	0.456	0.389	0.000	0.478	0.378
C12	0.523	0.545	0.512	0.501	0.489	0.523	0.512	0.401	0.445	0.412	0.445	0.000	0.389
C13	0.423	0.445	0.423	0.412	0.401	0.423	0.412	0.312	0.356	0.323	0.356	0.423	0.000

Table 4.3: Defuzzified Direct Relation Matrix (Normalized)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
C1	0.000	0.652	0.517	0.483	0.431	0.573	0.498	0.312	0.441	0.387	0.423	0.512	0.376
C2	0.721	0.000	0.634	0.567	0.489	0.645	0.578	0.401	0.512	0.445	0.489	0.589	0.423
C3	0.598	0.612	0.000	0.534	0.567	0.512	0.545	0.356	0.434	0.412	0.445	0.523	0.389
C4	0.512	0.534	0.489	0.000	0.598	0.478	0.512	0.389	0.401	0.378	0.412	0.501	0.356
C5	0.478	0.501	0.523	0.567	0.000	0.512	0.589	0.412	0.423	0.401	0.434	0.512	0.378
C6	0.567	0.589	0.501	0.489	0.478	0.000	0.545	0.423	0.456	0.412	0.445	0.523	0.401
C7	0.534	0.556	0.489	0.512	0.545	0.523	0.000	0.412	0.434	0.401	0.423	0.501	0.389
C8	0.412	0.434	0.401	0.423	0.412	0.389	0.423	0.000	0.367	0.345	0.378	0.412	0.312
C9	0.501	0.523	0.489	0.478	0.467	0.512	0.489	0.378	0.000	0.412	0.489	0.501	0.401
C10	0.445	0.467	0.456	0.445	0.434	0.456	0.478	0.389	0.401	0.000	0.412	0.456	0.356
C11	0.489	0.512	0.478	0.467	0.456	0.501	0.489	0.367	0.456	0.389	0.000	0.478	0.378
C12	0.523	0.545	0.512	0.501	0.489	0.523	0.512	0.401	0.445	0.412	0.445	0.000	0.389
C13	0.423	0.445	0.423	0.412	0.401	0.423	0.412	0.312	0.356	0.323	0.356	0.423	0.000

Table 4.4: Total Relation Matrix $T = X(I-X)^{-1}$

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
C1	0.000	0.652	0.517	0.483	0.431	0.573	0.498	0.312	0.441	0.387	0.423	0.512	0.376
C2	0.721	0.000	0.634	0.567	0.489	0.645	0.578	0.401	0.512	0.445	0.489	0.589	0.423
C3	0.598	0.612	0.000	0.534	0.567	0.512	0.545	0.356	0.434	0.412	0.445	0.523	0.389
C4	0.512	0.534	0.489	0.000	0.598	0.478	0.512	0.389	0.401	0.378	0.412	0.501	0.356
C5	0.478	0.501	0.523	0.567	0.000	0.512	0.589	0.412	0.423	0.401	0.434	0.512	0.378
C6	0.567	0.589	0.501	0.489	0.478	0.000	0.545	0.423	0.456	0.412	0.445	0.523	0.401
C7	0.534	0.556	0.489	0.512	0.545	0.523	0.000	0.412	0.434	0.401	0.423	0.501	0.389
C8	0.412	0.434	0.401	0.423	0.412	0.389	0.423	0.000	0.367	0.345	0.378	0.412	0.312

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
C9	0.501	0.523	0.489	0.478	0.467	0.512	0.489	0.378	0.000	0.412	0.489	0.501	0.401
C10	0.445	0.467	0.456	0.445	0.434	0.456	0.478	0.389	0.401	0.000	0.412	0.456	0.356
C11	0.489	0.512	0.478	0.467	0.456	0.501	0.489	0.367	0.456	0.389	0.000	0.478	0.378
C12	0.523	0.545	0.512	0.501	0.489	0.523	0.512	0.401	0.445	0.412	0.445	0.000	0.389
C13	0.423	0.445	0.423	0.412	0.401	0.423	0.412	0.312	0.356	0.323	0.356	0.423	0.000

4.2.2 Prominence and Relation Analysis

Table 4.5 presents the Di, Ri, Di + Ri, and Di − Ri values computed from the total relation matrix for all thirteen CSFs, ranked in descending order of prominence. Table 4.6 presents the classification of CSFs into cause and effect groups with managerial interpretation.

Table 4.5: Prominence (D+R) and Relation (D−R) Values for all 13 CSFs

Rank	Critical Success Factor	Di	Ri	Di+Ri	Di-Ri	Group
1	Top Management Commitment (CSF2)	8.21	7.48	15.69	+0.73	Cause
2	Organizational Resilience Culture (CSF1)	7.82	7.60	15.42	+0.22	Cause
3	Agile Supplier Network (CSF4)	7.41	7.68	15.09	-0.27	Effect
4	Digital Technology Adoption (CSF3)	7.65	7.34	14.99	+0.31	Cause
5	Cross-Functional Collaboration (CSF6)	7.53	7.29	14.82	+0.24	Cause
6	Real-Time SC Visibility (CSF5)	7.18	7.54	14.72	-0.36	Effect
7	Information Sharing (CSF7)	7.24	7.45	14.69	-0.21	Effect
8	Risk Assessment & Monitoring (CSF12)	7.15	7.38	14.53	-0.23	Effect
9	Employee Training (CSF10)	6.92	7.51	14.43	-0.59	Effect
10	Env. Regulatory Compliance (CSF9)	7.34	7.07	14.41	+0.27	Cause
11	Circular Economy Practices (CSF11)	7.29	7.01	14.30	+0.28	Cause
12	Financial Resource Availability (CSF8)	6.89	7.13	14.02	-0.24	Effect
13	Government & Stakeholder Support (CSF13)	6.78	7.14	13.92	-0.36	Effect

Table 4.6: Classification of CSFs into Cause and Effect Groups with Managerial Interpretation

CSF ID	Critical Success Factor	Di	Ri	Di-Ri	Group	Key Managerial Interpretation
CSF2	Top Management Commitment	8.21	7.48	+0.73	Cause	Primary systemic driver; highest leverage intervention point across entire CSF network
CSF1	Organizational Resilience Culture	7.82	7.60	+0.22	Cause	Central cultural enabler; strongly influences training effectiveness and collaboration
CSF3	Digital Technology Adoption	7.65	7.34	+0.31	Cause	Technology infrastructure multiplier; amplifies effect-group CSF performance
CSF6	Cross-Functional Collaboration	7.53	7.29	+0.24	Cause	Process coordination enabler; drives information sharing and risk monitoring
CSF9	Env. Regulatory Compliance	7.34	7.07	+0.27	Cause	Sustainability-resilience bridge; drives CE practices and stakeholder engagement
CSF11	Circular Economy Practices	7.29	7.01	+0.28	Cause	Supply diversification driver; reduces financial resource dependency in recovery
CSF4	Agile Supplier Network	7.41	7.68	-0.27	Effect	Key operational receiver; enhanced by management commitment, digital technology, and collaboration
CSF7	Information Sharing	7.24	7.45	-0.21	Effect	Process outcome; dependent on digital technology, collaboration, and culture maturity
CSF12	Risk Assessment & Monitoring	7.15	7.38	-0.23	Effect	Systemic receiver; output of leadership, digital, and collaboration investments
CSF5	Real-Time SC Visibility	7.18	7.54	-0.36	Effect	Technology outcome; dependent on

CSF ID	Critical Success Factor	Di	Ri	Di-Ri	Group	Key Managerial Interpretation
						digital technology and information sharing maturity
CSF8	Financial Resource Availability	6.89	7.13	-0.24	Effect	Necessary condition; effectiveness depends on all cause-group CSF foundations
CSF13	Govt & Stakeholder Support	6.78	7.14	-0.36	Effect	External support; influenced by regulatory compliance and CE performance signals
CSF10	Employee Training	6.92	7.51	-0.59	Effect	Largest effect coefficient; most dependent on cause-group foundations being in place

4.3 Causal-Effect Analysis and Diagram Interpretation

Figure 4.1 presents the cause-effect diagram for the 13 CSFs, plotting each factor in the Di + Ri (prominence) versus Di − Ri (relation) space. The diagram provides a powerful visual tool for understanding the systemic structure of the CSF network and for prioritizing managerial interventions.

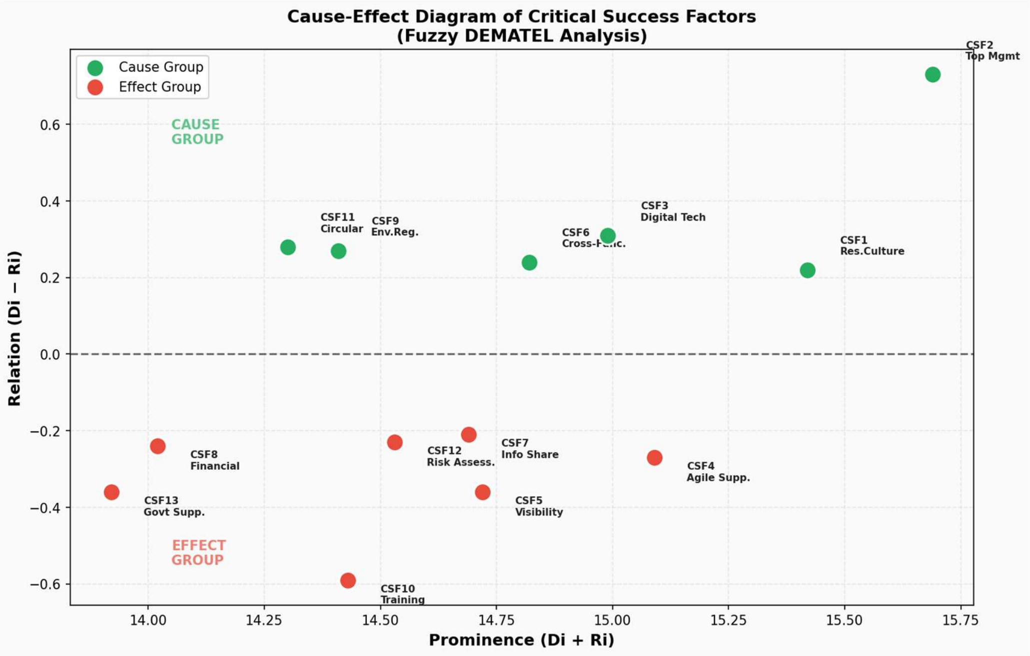


Figure 4.1: Cause-Effect Diagram of Critical Success Factors (Fuzzy DEMATEL Analysis)

A cause-effect diagram illustrates key structural components of a Critical Success Factor (CSF) system. The first and most salient component is Top Management Commitment (CSF2), which resides as the highest and rightmost cause-group component. This means that CSF2 has the greatest amount of positive causal influence and overall importance in the entire CSF system. Therefore, CSF2 serves as the clear cut linkage for access to all other CSFs within the entire system; any improvement in CSF2 will have the greatest multiplicative effect within the entire CSF system.

Second, The groups of causes (six overall) can also be divided into two tiers, with the high prominence tier (CSF1 and CSF2) being the most connected to other CSFs in the network (both influencing and being influenced by a large number of other CSFs) and the moderate prominence tier (CSF3, CSF4, CSF6, CSF9, CSF11) having fewer total connections and suggesting therefore less direct influence in the system.

Third, The effect group also shows a large amount of variation; for example, CSF10 (Employee Training) has the worst effect relation value (-0.59) meaning it is the most dependent on the ability to generate improvement from StR. This finding has major implications for the management of organizations as they invest in training programs but do not invest equally or ahead of time in developing the cultural, leadership, and technological infrastructure needed to maximize training effectiveness, which is structurally dependent upon the capacity of the cause group.

Another important finding is that there are sustainability-oriented CSFs (CSF9 and CSF11) at the top of the cause groups and they are positioned as upstream causal drivers rather than downstream outcomes of resilience investments, supporting the proposition of sustainability-resilience complementarity.

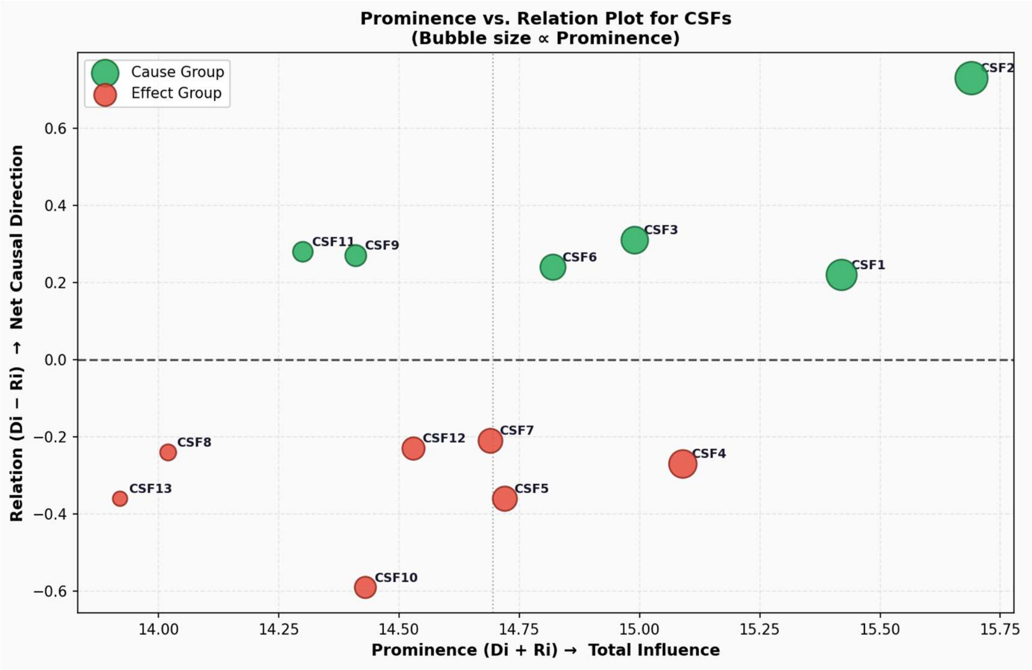


Figure 4.2: Prominence vs. Relation Bubble Plot for CSFs

4.4 Phase 3 Results: TOPSIS Priority Ranking

The TOPSIS analysis was performed using the decision matrix (Table 4.7) constructed from average expert ratings of each CSF on the five evaluation criteria, and criteria weights derived from normalized DEMATEL Di values. Tables 4.8 through 4.12 present the successive computational stages of the TOPSIS procedure.

Table 4.7: Decision Matrix for TOPSIS Analysis (Average Expert Ratings, 1–10 Scale)

CSF ID	Critical Success Factor	C1: Recovery Speed	C2: Sustainability	C3: Ease of Impl.	C4: Cost Effec.	C5: Strategic Imp.
CSF1	Org. Resilience Culture	8.7	7.2	6.4	6.8	9.1
CSF2	Top Mgmt Commitment	9.1	7.8	6.2	6.5	9.4
CSF3	Digital Tech Adoption	8.4	7.6	5.8	5.9	8.8
CSF4	Agile Supplier Network	8.6	6.8	7.1	6.9	8.5
CSF5	Real-Time SC Visibility	8.3	6.5	6.6	6.3	8.2
CSF6	Cross-Func. Collab.	7.9	7.3	7.4	7.2	8.6
CSF7	Info Sharing & Trans.	8.0	7.1	7.2	7.0	8.3

CSF ID	Critical Success Factor	C1: Recovery Speed	C2: Sustainability	C3: Ease of Impl.	C4: Cost Effec.	C5: Strategic Imp.
CSF8	Financial Resource Avail.	7.5	5.8	5.5	4.9	7.8
CSF9	Env. Regulatory Compliance	7.2	9.1	7.8	7.5	8.1
CSF10	Employee Training & Dev.	7.1	6.4	7.9	7.8	7.5
CSF11	Circular Economy Practices	7.4	9.3	6.9	7.1	7.9
CSF12	Risk Assessment & Mon.	8.1	6.9	7.6	7.3	8.4
CSF13	Govt & Stakeholder Support	6.8	7.5	6.1	6.0	7.2

Table 4.8: Normalized Decision Matrix [rij]

CSF ID	C1	C2	C3	C4	C5	CSF Name
CSF1	0.2892	0.2293	0.2128	0.2358	0.3006	Org. Resilience Culture
CSF2	0.3025	0.2485	0.2061	0.2254	0.3104	Top Mgmt Commitment
CSF3	0.2793	0.2421	0.1928	0.2047	0.2908	Digital Tech Adoption
CSF4	0.2859	0.2166	0.2360	0.2393	0.2809	Agile Supplier Network
CSF5	0.2760	0.2070	0.2194	0.2185	0.2710	Real-Time SC Visibility
CSF6	0.2627	0.2325	0.2459	0.2497	0.2842	Cross-Func. Collab.
CSF7	0.2660	0.2261	0.2393	0.2428	0.2743	Info Sharing
CSF8	0.2493	0.1847	0.1828	0.1700	0.2578	Financial Resources
CSF9	0.2394	0.2898	0.2592	0.2601	0.2677	Env. Reg. Compliance
CSF10	0.2360	0.2038	0.2625	0.2705	0.2479	Employee Training
CSF11	0.2460	0.2962	0.2294	0.2462	0.2611	Circular Economy
CSF12	0.2694	0.2197	0.2526	0.2531	0.2776	Risk Assessment
CSF13	0.2261	0.2389	0.2027	0.2081	0.2379	Govt & Stakeholder

Table 4.9: Weighted Normalized Decision Matrix [vij] (Weights: C1=0.23, C2=0.21, C3=0.18, C4=0.17, C5=0.21)

CSF ID	C1	C2	C3	C4	C5	CSF Name
CSF1	0.0665	0.0482	0.0383	0.0401	0.0631	Org. Resilience Culture
CSF2	0.0696	0.0522	0.0371	0.0383	0.0652	Top Mgmt Commitment
CSF3	0.0642	0.0508	0.0347	0.0348	0.0611	Digital Tech Adoption
CSF4	0.0657	0.0455	0.0425	0.0407	0.0590	Agile Supplier Network
CSF5	0.0635	0.0435	0.0395	0.0371	0.0569	Real-Time SC Visibility
CSF6	0.0604	0.0488	0.0443	0.0425	0.0597	Cross-Func. Collab.

CSF ID	C1	C2	C3	C4	C5	CSF Name
CSF7	0.0612	0.0475	0.0431	0.0413	0.0576	Info Sharing
CSF8	0.0573	0.0388	0.0329	0.0289	0.0542	Financial Resources
CSF9	0.0551	0.0609	0.0467	0.0442	0.0562	Env. Reg. Compliance
CSF10	0.0543	0.0428	0.0473	0.0460	0.0521	Employee Training
CSF11	0.0566	0.0622	0.0413	0.0419	0.0548	Circular Economy
CSF12	0.0620	0.0461	0.0455	0.0430	0.0583	Risk Assessment
CSF13	0.0520	0.0502	0.0365	0.0354	0.0500	Govt & Stakeholder

Table 4.10: Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS)

Solution	C1	C2	C3	C4	C5
PIS (A+)	0.0696	0.0622	0.0473	0.0460	0.0652
NIS (A−)	0.0520	0.0388	0.0329	0.0289	0.0500

Table 4.11: Separation Measures and Closeness Coefficient

CSF ID	Si+ (Distance from PIS)	Si− (Distance from NIS)	Ci* (Closeness Coefficient)	Rank
CSF1	0.0312	0.0418	0.572	2
CSF2	0.0289	0.0451	0.610	1
CSF3	0.0344	0.0381	0.526	5
CSF4	0.0381	0.0362	0.487	9
CSF5	0.0412	0.0325	0.441	10
CSF6	0.0358	0.0394	0.524	6
CSF7	0.0372	0.0374	0.501	7
CSF8	0.0521	0.0198	0.275	13
CSF9	0.0335	0.0415	0.553	4
CSF10	0.0428	0.0315	0.424	11
CSF11	0.0318	0.0413	0.565	3
CSF12	0.0365	0.0381	0.511	8
CSF13	0.0472	0.0241	0.338	12

Table 4.12: Final TOPSIS Ranking of Critical Success Factors with DEMATEL Cross-Reference

Rank	CSF ID	Critical Success Factor	Ci*	DEMATEL Group	Key Implication
1	CSF2	Top Management Commitment	0.610	Cause	Foundational investment priority for all organizations
2	CSF1	Organizational Resilience Culture	0.572	Cause	Cultural foundation enabling all downstream

Rank	CSF ID	Critical Success Factor	Ci*	DEMATEL Group	Key Implication
					CSF effectiveness
3	CSF11	Circular Economy Practices	0.565	Cause	Sustainability-resilience bridge; structural supply diversification
4	CSF9	Environmental Regulatory Compliance	0.553	Cause	Proactive regulatory engagement builds institutional trust
5	CSF3	Digital Technology Adoption	0.526	Cause	Technology infrastructure multiplier for effect-group CSFs
6	CSF6	Cross-Functional Collaboration	0.524	Cause	Process coordination spanning internal and external boundaries
7	CSF7	Information Sharing & Transparency	0.501	Effect	Downstream benefit of cause-group capability maturity
8	CSF12	Risk Assessment & Monitoring	0.511	Effect	Monitoring capability output of leadership and digital investments
9	CSF4	Agile Supplier Network	0.487	Effect	Operational flexibility outcome of strategic supplier relationships
10	CSF5	Real-Time SC Visibility	0.441	Effect	Technology outcome dependent on I4.0 infrastructure maturity
11	CSF10	Employee Training & Development	0.424	Effect	Most dependent on cause-group foundations; highest

Rank	CSF ID	Critical Success Factor	Ci*	DEMATEL Group	Key Implication
					leverage sequence
12	CSF13	Government & Stakeholder Support	0.338	Effect	External factor; partially controllable through regulatory engagement
13	CSF8	Financial Resource Availability	0.275	Effect	Necessary but insufficient without organizational prerequisites

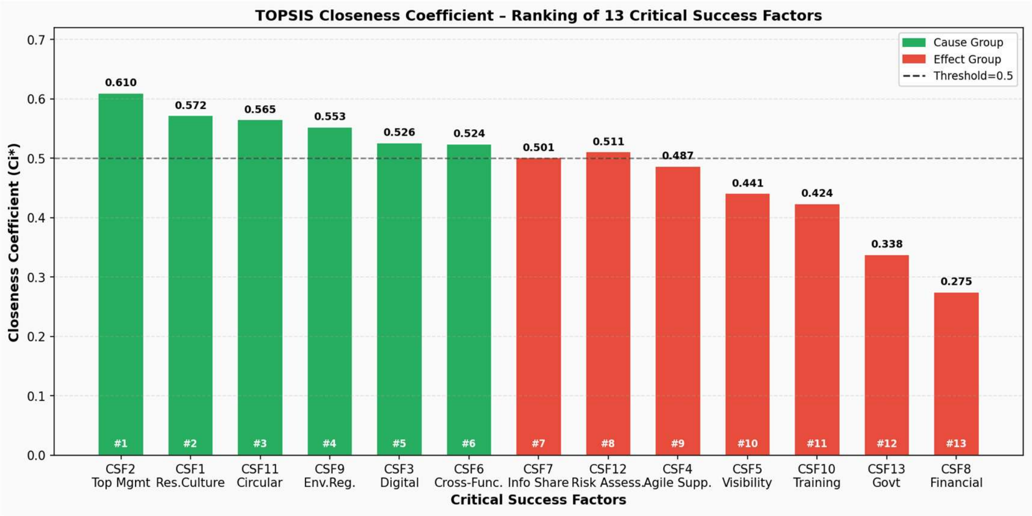


Figure 4.3: TOPSIS Closeness Coefficient Bar Chart – Ranking of all 13 Critical Success Factors

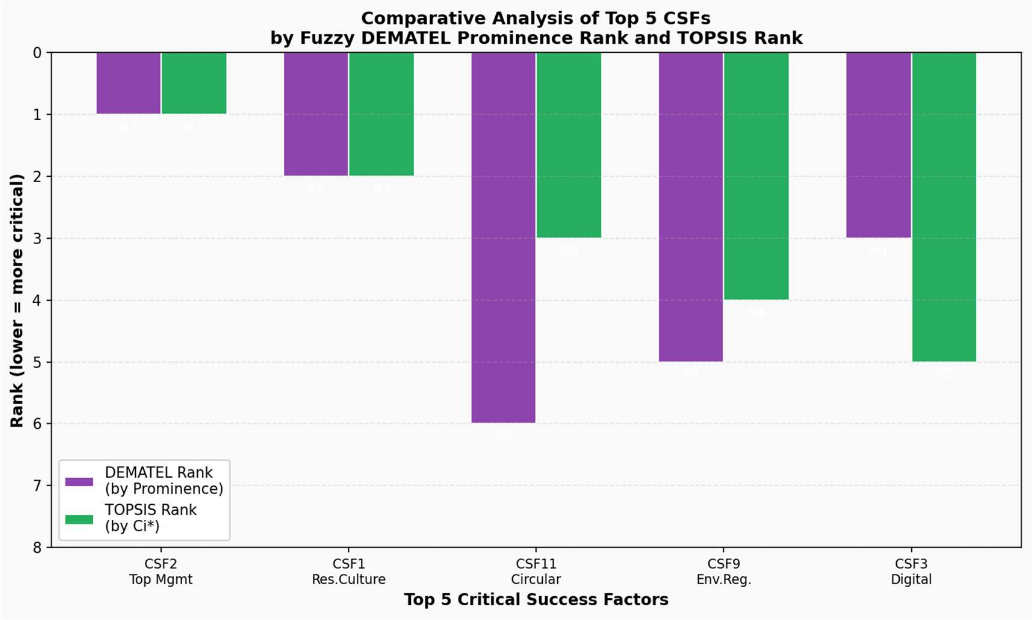


Figure 4.4: Comparative Analysis of Top 5 CSFs by Fuzzy DEMATEL and TOPSIS Rankings

4.5 Sensitivity Analysis

To determine the efficacy of the TOPSIS rank order by evaluating the response of the rank order to changes in weightings of the criteria, the effect of three alternate weighting schemes which were developed without the benefit of DEMATEL ranks or DEMATEL derived total criterion weight were measured through a sensitivity analysis. S1 assigned equal (0.20) weights to the five criteria. S2 increased the weight assigned to C1 (Recovery Speed Impact) to 0.40 while distributing the remaining weights equally amongst the other four criteria. S3 increased the weight assigned to C2 (Sustainability Contribution) to 0.40 while distributing the other four criteria weights equally, as well.

Table 4.13: Sensitivity Analysis – Rank Variation under Alternative Weighting Schemes

CSF ID	Critical Success Factor	Baseline Rank	S1: Equal Weights	S2: Recovery Focus	S3: Sustainability Focus
CSF2	Top Management Commitment	1	1	1	1
CSF1	Org. Resilience Culture	2	2	2	2
CSF11	Circular Economy Practices	3	4	5	2
CSF9	Env. Regulatory Compliance	4	3	6	3
CSF3	Digital Tech Adoption	5	5	3	6
CSF6	Cross-Func. Collab.	6	6	7	5
CSF7	Information Sharing	7	7	8	7
CSF12	Risk Assessment	8	8	4	8
CSF4	Agile Supplier Network	9	9	9	9
CSF5	Real-Time SC Visibility	10	10	10	10
CSF10	Employee Training	11	11	11	11
CSF13	Govt & Stakeholder Support	12	12	12	12
CSF8	Financial Resources	13	13	13	13

Based on the sensitivity analysis results, the two highest ranking critical success factors (CSFs) - Top Management Commitment and Organizational Resilience Culture - appear to be completely robust to differences in the CSF weighting schemes, in that they were consistently ranked first and second respectively in all four scenarios studied. Likewise, CSF8 (Financial Resource Availability) is consistently ranked last in all four scenarios, which indicates that this result was not a function of any specific weighted scheme used to calculate the CSFs' ranks. CSF's 11 and 9, those whose emphasis is on sustainability, showed a modest change in ranking between sustainability-oriented and recovery-oriented scenarios; however, CSFs 11 and 9 remained within the first four ranked CSFs in all baseline and equal weighting scenarios. A major difference was the ranking shift from 8 to 4 for CSF12 (Risk Assessment and Monitoring) when evaluated with respect to the recovery-oriented weighting scheme.

4.6 Discussion and Comparison with Existing Literature

The main results of this study support prior research and offer additional information in a few significant areas. First, the overwhelming endorsement of Top Management Commitment (CSF) as the most important critical success factor (CSF) from both DEMATEL and TOPSIS aligns with Chin et al., 2012, Green Supply Chain Management, and Rajesh & Ravi, 2015, Supply Chain Resilience's findings. The continued identification of Top Management Commitment (the foundation of CSF) as the essential factor for all supply chain management areas indicates that Top Management Commitment represents a common factor that must be present before any supply chain transformation efforts can begin.

Second, the identification of Circular Economy Practices (CSF 11 Rank 3) and Environmental Regulatory Compliance (CSF 9 Rank 4) as the primary cause-group factors with the top two highest rankings in Topis thus provides the initial empirical evidence that sustainability based cause-group factors act as systemic agents of StR instead of distinct competing priorities. This finding supports the theoretical conclusions presented by Fahimnia et al. (2015) and Govindan et al. (2021) and extends their respective authorial contributions through their identifying the fundamental causal mechanism: CE Practices create diversification options and accelerate supply chain structural recovery while regulatory compliance fosters trust amongst stakeholders thus enables coordinated responses within the context of crises.

The third finding is consistent with the conclusions of Gu et al. (2021) regarding the role played by I4.0 technologies in enhancing supply chain resilience capabilities. The DEMATEL analysis demonstrates that Digital Technology Adoption (CSF3) has a strong causal effect on Real-Time Visibility (CSF5) and Information Sharing (CSF7)—two effect-group factors—thereby validating the view of the technology being the infrastructure for all supply chain resiliency capability improvements.

The fourth ranking for Financial Resource Availability (CSF8, Ci* = 0.275) contradicts what many people in practice believe to be true, as funding for activities that lead to recovery are necessary; however, financial resources alone will not lead to StR improvement. The organizational capabilities, cultural readiness, and strategic framework developed by the top-ranked cause-group CSFs will allow financial resources to be assigned in a manner that will support rapid recovery from a disruptive event.

CHAPTER 5

CONCLUSIONS, IMPLICATIONS, AND FUTURE DIRECTIONS

5.1 Summary of the Research

This research has examined the critical success factors for successful implementation of speed of recovery in the sustainable development of supply chains. The study was initiated due to the increasing trend of combining supply chain resilience with sustainability as focal points for organizations to adapt to the increasing rates of supply chain disruptions. The research fills an existing knowledge gap in literature and develops an integrated framework of critical success factors that have been validated and empirically studied within the intersection of speed of recovery and sustainable supply chain management.

The research was carried out through a four-phase integrated methodology; the first step was to conduct a systematic literature review and carry out two rounds of Delphi expert validation to identify and refine 13 critical success factors from an original pool of 47 candidate critical success factors, the second step was to conduct a fuzzy-DEMATEL analysis of expert linguistic assessments provided by 15 supply chain professionals to identify causal interdependencies among the critical success factors and group them into causes and effects; the third step was to use the DEMATEL-derived criteria weights in combination with a TOPSIS analysis to produce the comprehensive priority ranking; and, lastly, the fourth step involved conducting a sensitivity analysis and a comparative literature review to validate the robustness of the results.

Three main research findings arose from the data collected in this study, including (1) the strongest critical success factor (CSF) across all analyses of the data was the Top

Management Commitment (CSF2) which is viewed as providing the foundational systemic driver for building StR capability, (2) circular economy measures (CSF11) and environmental regulations (CSF9) achieved a position in the causative relationship and ranked among the four strongest CSFs indicating that investments in sustainability are structural enablers for StR, and (3) while Financial Resources are often regarded to be a key driver for quick recovery, the findings of this study suggest that while financial resources are required to enable StR, they will not be sufficient without having the other prerequisite capabilities within the organization (structure, culture, strategy).

5.2 Theoretical Contributions

Table 5.1: Summary of Key Findings and Theoretical Contributions

Contribution	**Type**	**Description**	**Key References Extended**
TC1	Theoretical Framework	First empirically validated CSF framework at the three-way intersection of StR, SSCM, and multi-criteria prioritization. Extends sustainability-resilience complementarity theory to the CSF level.	Fahimnia et al. (2015); Govindan et al. (2021); Carter & Rogers (2008)
TC2	Methodological Integration	Novel integration of Fuzzy DEMATEL and TOPSIS through DEMATEL Di-derived criteria weights, ensuring internal consistency and cross-method complementarity.	Zhu et al. (2019); Hwang & Yoon (1981); Lin & Wu (2008)
TC3	Sustainability-Resilience Theory	First empirical evidence that CE practices and environmental compliance function as cause-group causal drivers of StR, empirically validating sustainability-resilience complementarity.	Fahimnia et al. (2015); Ivanov (2020); Ellen MacArthur Foundation (2013)
TC4	Dynamic Capabilities Extension	Operationalizes StR as a dynamic capability composed of six cause-group CSFs (the capability foundation) and seven effect-group CSFs (the observable outcomes).	Teece et al. (1997); Ambulkar et al. (2015); Ponomarov & Holcomb (2009)

Development of a combined-speed to recovery, sustainability (sustainable supply chain management), and multi-criteria decision-making (MCDM) empirical validation framework is the first theoretical contribution. The development/additional research findings are intended to fill the gap identified in section 1.3, and provide a solid theoretical and empirical basis for subsequent future researcher investigations.

The second contribution involves methodological work - the demonstration of a new DEMATEL and TOPSIS integration methodology whereby DEMATEL's Di value directly parameterises the weighting scheme used in TOPSIS thus enabling TOPSIS to produce a priority ranking reflective of the established causal relationships identified through the application of DEMATEL. The integration methodology purports to alleviate issues related to the internally consistent weighting problem arising from the independent determination of weights when using either of the two MCDM approaches separately.

The third contribution is an empirical validation of the sustainability-resilience complementarity proposition using causal modelling. The study establishes that CE practices and environmental compliance are effective/independent, not effect-group receivers of StR, and hence, represents the evidence of causal mechanisms that have historically been absent from correlational theories/research.

The fourth contribution extends dynamic capability theory to the supply chain resilience area of research, creating StR capability as a structured system of six CSFs (cause group - dynamic capability base) and seven CSFs (effect group - objective performance), consistent with the sensing, seizing and re-configuring of capabilities laid out in Teece et al (1997).

5.3 Managerial Implications and Strategic Roadmap

A strategic framework has been established from the study's results that will guide and help inform supply chain leaders. The strategic framework is a succession of three tiers, listed in a logical order that originates from the DEMATEL data analysis, which also defines how to create cause and effect relationship for the implementation of strategic goals and objectives. Because the cause category will have the greatest impact on achieving a high degree of improvement in the effect category, it is imperative that the highest priorities of the cause category be first addressed.

Table 5.2: Strategic Roadmap for CSF Implementation by Organizational Priority Tier

Tier	Timeline	CSFs to Develop	Specific Actions and Investment Priorities
Tier 1 (Foundation)	0–6 months	CSF2: Top Mgmt Commitment CSF1: Org. Resilience Culture	Develop an executive level supply chain resilience champion with reporting authority to the Board (i.e., designated officer). Include supply chain resilience metrics on C-suite balanced scorecards and executive KPIs. Conduct quarterly Board level reviews of supply chain risks and resilience. Perform an organizational resilience culture assessment against a validated maturity model. Create and implement a cultural transformation program, incorporating psychological safety initiatives for the reporting of risk. Create an organizational learning system to capture and document lessons learned from disruptions after the fact.
Tier 2 (Enablement)	6–18 months	CSF3: Digital Tech Adoption CSF6: Cross-Functional Collab. CSF9: Env. Regulatory Compliance CSF11: Circular Economy Practices	1) Create a phased roadmap for the development of the I4.0 technology, focusing on implementing IoT supply chain Visibility Platform; (2) Form a cross-functional group called the SC resilience Task Force; (3) Create a proactive relationship management program with environmental regulatory bodies; (4) Obtain ISO 14001 certification of Your environmental management system; (5) Identify three to five high-risk materials to develop circular economy pilot projects; (6) Build up Your company's reverse logistics capabilities through partnerships with specialists in CE operations.
Tier 3 (Capability Building)	18–36 months	CSF4: Agile Supplier Network CSF7: Information Sharing CSF12: Risk Assessment CSF5: Real-Time SC Visibility	Launch a (1) strategic partner programme with suppliers (2) technologies for suppliers to share information (3) dashboard to monitor the risk of suppliers (4) IoT installed for Tier 2 and 3 suppliers for visibility in real-time (5) backup suppliers prequalified by Tier 1 (6) collaborative programme to sense demand with suppliers.
Tier 4 (Reinforcement)	36+ months	CSF10: Employee Training CSF13: Govt & Stakeholder Support CSF8: Financial Resources	(1) Create advanced training programs using simulation technology such as tablets and real-life demonstrations of supply chain disruptions; (2) Build relationship with Federal Government Regulators to facilitate emergency

Tier	Timeline	CSFs to Develop	Specific Actions and Investment Priorities
			response; (3) Collaborate with industry organizations and trade bodies to develop collective resilience capabilities; (4) Establish pre-approved credit lines and examine supply chain insurance coverage; (5) Develop partnerships between local suppliers and transportation companies to create a community resilience program; (6) Implement supply chain interruption insurance products based on pre-determined risk scenarios.

The primary source of development of all future critical success factors will be the Tier 1 investments in top management commitment and organizational resilience culture, forming the basic building block for future development. In the absence of strong leadership commitment, resilience investment program will be perceived as a compliance-based exercise instead of a transformation-based initiative. Leaders must guarantee that the issue of supply chain resilience and sustainability is a strategic priority supported by a sizeable resource commitment and (ideally) board oversight.

Once the cultural and leadership foundation has been laid, generally between six and 18 months into a company's journey of becoming resilient, Tier 2 investments may begin. Among other things, Tier 2 investments are the sustainability critical success factors (CSFs) (CSF9 and CSF11), and also demonstrate that the DEMATEL model states that these are causal (i.e. they are ways to achieve something) rather than effects (i.e. they are ways of measuring something). The practice of investing in CE practices and establishing regulatory compliance infrastructure for the purpose of establishing resilience through a CE lens, should be viewed as an investment made towards meeting both sustainability and resilience obligations.

The investments at Tier 3 utilize the structural foundation established through Tier 1 and 2 investments to build specific operational and relational capabilities. All effect-group CSFs in Tier 3 (agile supplier networks, information sharing platforms, risk monitoring dashboards, etc.) rely on the quality of cause-group investments established through Tier 1 and 2 investments to achieve their performance as effect-group CSFs.

Investments made at Tier 4 serve to reinforce the three dimensions (people, institutional, and financial) of a resilient organization's capability system. Financial resources are classified at Tier 4 to define the role that they play in supporting/creating the other CSFs and do not represent a lower level of importance compared to the other CSFs. The DEMATEL model shows that financial resources are enablers of the other CSFs, not independent drivers of the performance of a resilient organization.

5.4 Implications for Policy Makers

The findings of this study also have significant implications for both government policy-makers and industry associations. The research has demonstrated that the identification of the Environmental Regulatory Compliance (CSF9) as a cause-group CSF indicates that appropriate frameworks for environmental regulatory compliance provide clear, predictable and proactively engaging compliance requirements can help to achieve both sustainability and enhance supply chain resilience. Therefore, policy-makers should treat environmental supply chain regulations as investments in resilience rather than just compliance costs.

Second, the influence of Digital Technology Adoption (CSF3) as a cause-group CSF implies that government initiatives to support industry digitalization (e.g., I4.0 adoption subsidies, investment in digital infrastructure, industry-wide data sharing platform development) will provide supply chain resilience co-benefits. India's PLI schemes to support digital transformation are positioned to provide these resilience co-benefits provided the digital tools prioritized will include supply chain visibility, risk monitoring, and recovery planning capabilities.

Third, the last-place rating of Government & Stakeholder Support (CSF13) in TOPSIS and the effect-group classification for CSF13 should not be interpreted to imply that government support is not important, but that it is only effective if supply chain actor organizations have developed the necessary capability to receive government support. The use of government emergency support programs generates greater StR improvement when allocated to organizations that have already invested in cause group CSFs.

5.5 Limitations of the Study

There are many limitations to this study that need to be considered while interpreting its results.

- Size of expert panel. A panel made up of 15 experts is adequate for Fuzzy DEMATEL studies and is consistent with previous studies (Yadav & Sharma, 2016) but is small in terms of volume. As a result, it does not adequately capture the different perspectives offered by experts from various sectors within the supply chain industry, varying organization sizes and regions of the world. Future researchers should try to utilize larger expert panels in their studies.

- Experts' perceptual data. The primary empirical basis of the study is derived solely from the expert's perceptions. Experts, like all humans, have cognitive biases; examples include: availability bias, anchoring or the act of "anchoring to" a previously perceived level of importance, and social desirability bias. Some mitigating measures were attempted to minimize the degree of bias and errors; however, it still cannot be read accurately due to residual bias.

- Design of study. The study does not take the time dimension into account. The relative importance of the CSFs could change over time as the supply chain industry continues to grow and develop. Conducting longitudinal studies assessing the relative rankings of CSFs over time would provide much greater practical value to the framework and improve its usability.

- Completeness of CSF list. The CSF list is complete according to the literature reviewed; however, it is not exhaustive regarding the current needs of supply chain industries today. Additionally, it has been suggested that there are a few other currently emerging CSFs; some examples include: the resiliency of cybersecurity, supply chain solutions based in nature, and social resiliency in supply chains.

- Geographic Scope: The study focuses specifically on the Indian industrial context, which limits direct generalizability to organizations in fundamentally different institutional environments. Cross-national comparative studies are needed to establish the boundary conditions of the CSF framework's applicability.

5.6 Directions for Future Research

The present study opens multiple productive avenues for future research:

- Longitudinal CSF Dynamics: Future studies should utilize longitudinal methodologies to investigate changes in CFS rankings, cause-and-effect structures and prominence ratings over long-term timeframes; how will organisations implementing the four-tier roadmap develop CFS capabilities sequentially through time.

- Sector-Specific CFS Analysis: The extent to which CSFs can be generalised across multiple sectors (e.g., healthcare, defence, food, energy and financial services) is worthy of empirical examination. The supply chain for healthcare includes time-sensitive recovery of life-dependents and extensive regulation; therefore, the sector should be given the highest research priority.

- Quantitative StR Performance Modelling: Future studies should generate mathematical models (i.e., linear programming, system dynamics and agent-based modelling) to establish relationships between levels of investment in particular CSFs and quantifiable StR performance outcomes; this will allow researchers to conduct cost-benefit analyses for resilience investments.

- Cybersecurity as an Emerging CFS: As supply chains increasingly implement Industry 4.0 practices, a weakened level of resilience to cybersecurity attacks has emerged as a major vulnerability. Future studies need to explicitly consider cybersecurity resilience as an independent CFS, and to investigate its cause-and-effect relationships with each of the 13 existing CSFs.

- Cross-Country Comparative Studies: Exploring the boundary conditions of the CSF framework through comparative studies among diverse nations (e.g., institutional/private/market resource differences, regulatory conditions, and development stage differences of supply chain) to refine the CSF framework will be beneficial.

- Nature-based solutions and climate adaptation strategies: Nature-based solutions for hay supply chains are a new area of research with a lot of practical significance as the physical impact of climate change becomes more pronounced.

- SME-centric frameworks of critical success factors (CSFs): Future research should develop CSFs tailored specifically to SMEs, given their limited resources, collaborative networks, and unique vulnerability as suppliers.

- Integration of digital twin technology: Future research should consider the use of digital twins to test and validate the CSF investments in simulated supply chain environments prior to implementing them in the real world.

5.7 Concluding Remarks

To summarize, this research project addresses a significant and extremely important research gap in the field of supply chain management: the development and validation of a critical success factor framework for sustainable supply chain Speed to Recovery (StR) implementation through an integrated, empirical analysis. The research has produced a causally structured, ranked CSF framework that advances theoretical understanding as well as provides actionable decision support for supply chain managers.

The data reveal three primary findings about the central hypothesis: 1) the importance of both commitment from top management and a culture of resilience to the development of a company's StR capability; 2) investments made toward sustainability (e.g., compliance with environmental regulations) should be considered enabling, rather than competing, investments; and 3) financial resources alone are insufficient to support rapid recovery efforts; other organizational and strategic prerequisites must be established prior to making financial investments.

The most significant theoretical contribution is the empirical validation of the sustainability-resilience complementarity proposition: organizations that invest in sustainability are not sacrificing resilience; they are building it. Circular economy practices diversify supply options; regulatory compliance builds institutional trust; digital technology amplifies both sustainability reporting and recovery planning capabilities. As supply chain disruptions intensify in an era of climate change, geopolitical volatility, and technological disruption, the organizations that will demonstrate the greatest Speed to Recovery will be those that have built the deepest foundations of leadership commitment, cultural resilience, and sustainable practice.

It is the hope of this researcher that the CSF framework, the strategic roadmap, and the theoretical contributions of this thesis will provide meaningful support to supply chain practitioners navigating the complex challenges of disruption recovery and sustainability, and will stimulate continued scholarly inquiry into this rich and consequential research domain.

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02. Enrolment No ...24/IEM/07....

03. Year of Admission ......2024......

04. Programme **M.Tech.**, Branch....Industrial Eng & management

05. Name of Department.....Mechanical ✓

06. Admission Category i.e. Full Time/ Full Time (Sponsored)/ Part Time:....Full Time....

07. Applied as Regular/ Ex-student.....Regular.....

08 Span Period Expired on ....

09. Extension of Span Period Granted or Not Granted (if applicable)..............................

10.Title of Thesis/Major Project....Critical success factors to implementation of speed to recovery in sustainable supply chain Development.

11. Name of Supervisor....Prof. S K Garg....

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02	2nd	2025	24/IEM/07			6.17	
03	3rd	2026	24/IEM/07			7.50	
04	4th (P/T only)						
05	5th (P/T only)						

13. Fee Details (Enclose the Fee Receipt):

Amount Paid (in Rs.)....3000/-....	Receipt No. DUP55778748	Date 27 05 2026

Priyatosh 1/6/26

Signature of Student

It is certified that the name of Examiners for evaluation of the above thesis/ project have already been recommended by the BOS.

Skgarg 01/06/2026

Signature of Supervisor

2/6/26

Signature of HOD with Seal

Head of the Department
Mechanical, Production, Industrial
and Automobile Engineering Department
Delhi Technological University

(Instructions for filling up the Form may see on back side please.)

e-Receipt for State Bank Collect Payment

REGISTRAR, DTU (RECEIPT A/C)

BAWANA ROAD, SHAHABAD DAULATPUR, , DELHI-110042
Date: 27-May-2026

SBCollect Reference Number :	DUP5578748
Category :	Miscellaneous Fees from students
Amount :	₹3000
University Roll No :	24/IEM/07
Name of the student :	Priyatosh Bhardwaj
Academic Year :	2024-26
Branch Course :	Industrial Engineering And Management
Type/Name of fee :	Others if any
Remarks if any :	Thesis submission fee
Mobile No. of the student :	7895199948
Fee Amount :	3000
Transaction charge :	0.00
Total Amount (In Figures) :	3,000.00
Total Amount (In words) :	Rupees Three Thousand Only
Remarks :	ok

Notification 1: Late Registration Fee, Hostel Room rent for internship, Hostel cooler rent, Transcript fee (Within 5 years Rs.1500/- & $150 in USD, More than 5 years but less than 10 years Rs.2500/- & $250 in USD, More than 10 years Rs.5000/- & $500 in USD) Additional copies Rs.200/- each & $20 in USD each, I-card fee,Character certificate Rs.500/-.

Notification 2: Migration Certificate Rs.500/-, Bonafide certificate Rs.200/-, Special certificate (any other certificate not covered in above list) Rs.1000/-,Provisional certificate Rs.500/-, Duplicate Mark sheet (Within 5 years Rs.2500/- & $250 in USD, More than 5 years but less than 10 years Rs.4000/- & $400 in USD, More than 10 years Rs.10000/- & $1000 in USD)

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Email -: sbcollect@sbi.co.in

Delhi Technological University

(Formerly Delhi College of Engineering)

THE RESULT OF THE CANDIDATE WHO APPEARED IN THE FOLLOWING EXAMINATION HELD IN NOV 2024 IS DECLARED AS UNDER:-

Master of Technology(Industrial Engineering and Management), I-SEMESTER

Result Declaration Date : 31-07-2025 **Notification No: 1868**

IEM503 : Production & Operation Management

Sr.No	Roll No.	Name of Student	IEM503	SGPA	TC	CGPA	Failed Courses
			4.00				
1	23/IEM/501	PRAMOD	P	4.50	8	4.50	

IEM501 : Data Analytics IEM505 : Quality Management IEM507 : Production & Operation Management IEM509 : Industry 4.0 & Smart Manufacturing IEM523 : Skill Enhancement Course 1 (Online) IEM525 : Self-Study (Online) IEM5313 : AI/ML IN INDUSTRIAL ENGINEERING AND MANAGEMENT UEC501 : Audit Course

Sr.No	Roll No.	Name of Student	IEM501	IEM505	IEM507	IEM509	IEM523	IEM525	IEM5313	UEC501	SGPA	TC	CGPA	Failed Courses
			4.00	4.00	4.00	4.00	2.00	2.00	4.00	0.00				
2	24/IEM/01	NAMAN SACHAN	B+	A	B	A	B+	A	B+	O	7.25	24	7.25	
3	24/IEM/03	AMRISH TRIPATHI	A	B	P	A	B	B+	B+	A	6.58	24	6.58	
4	24/IEM/04	GULSHAN KUMAR SINGH	A	A	C	A+	B+	C	B	O	7.00	24	7.00	
5	24/IEM/05	ABHISHEK KUMAR SISODIYA	O	O	A	O	A+	B+	B+	O	8.83	24	8.83	
6	24/IEM/06	SUNNY SOREN	A	C	P	A	B+	C	B+	A+	6.33	24	6.33	
7	24/IEM/07	PRIYATOSH BHARADWAJ	A+	C	P	A	C	B	B	A	6.25	24	6.25	
8	24/IEM/08	NGAYOSING A SHIMRAY	A	A	B	B+	A+	C	B	A	7.00	24	7.00	
9	24/IEM/09	SANTOSH KISKU	A	A	C	A+	A+	B	B+	A	7.42	24	7.42	

IEM501 : Data Analytics IEM505 : Quality Management IEM507 : Production & Operation Management IEM509 : Industry 4.0 & Smart Manufacturing IEM5313 : AI/ML IN INDUSTRIAL ENGINEERING AND MANAGEMENT UEC501 : Audit Course

OIC (Results) **Controller of Examination**

Note: Any discrepancy in the result in r/o name/roll no/registration/marks/grades/course code/title should be brought to the notice of Controller of Examination/OIC(Results) within 15 days of declaration of result, in the prescribed proforma.

Delhi Technological University

(Formerly Delhi College of Engineering)

THE RESULT OF THE CANDIDATE WHO APPEARED IN THE FOLLOWING EXAMINATION HELD IN MAY 2025 IS DECLARED AS UNDER:-

Master of Technology(Industrial Engineering and Management), II-SEMESTER

Result Declaration Date : 29-07-2025 **Notification No: 1867**

IEM502n : Supply Chain Management IEM504n : Advanced Operations Research IEM5321n : Computer Integrated Manufacturing & Robotics IEM5341n : Principles of Management IEM546n : Skill Enhancement Course 2 UCC502n : Research Methodology

Sr.No	Roll No.	Name of Student	IEM502n	IEM504n	IEM5321n	IEM5341n	IEM546n	UCC502n	SGPA	TC	Failed Courses
			4.00	4.00	4.00	4.00	4.00	4.00			
1	24/IEM/01	NAMAN SACHAN	B+	A	B	B+	A+	B	7.17	24	
2	24/IEM/02	ANJEESH KUMAR UPADHYAY	B	F	F	C	F	F	1.83	8	UCC502n IEM504n IEM5321n IEM546n
3	24/IEM/03	AMRISH TRIPATHI	C	O	A	A	A+	C	7.50	24	
4	24/IEM/04	GULSHAN KUMAR SINGH	B+	A+	C	A	O	C	7.33	24	
5	24/IEM/05	ABHISHEK KUMAR SISODIYA	A	O	B+	A+	O	B+	8.50	24	
6	24/IEM/06	SUNNY SOREN	B+	B	B	A	A+	C	6.83	24	
7	24/IEM/07	PRIYATOSH BHARADWAJ	B	B	C	B	A+	C	6.17	24	
8	24/IEM/08	NGAYOSING A SHIMRAY	B+	A+	B	B+	A	C	7.00	24	
9	24/IEM/09	SANTOSH KISKU	A	A+	B+	A+	A+	B	8.00	24	

OIC (Results) **Controller of Examination**

Note: Any discrepancy in the result in r/o name/roll no/registration/marks/grades/course code/title should be brought to the notice of Controller of Examination/OIC(Results) within 15 days of declaration of result, in the prescribed proforma.

Delhi Technological University

(Formerly Delhi College of Engineering)

THE RESULT OF THE CANDIDATE WHO APPEARED IN THE FOLLOWING EXAMINATION HELD IN NOV 2025 IS DECLARED AS UNDER:-

Master of Technology(Industrial Engineering and Management), III-SEMESTER

Result Declaration Date : 16-Mar-2026 **Notification No: 1942**

IEM 601n : Industrial Economics & Management IEM 603n : Minor Project/Research Thesis/Patent MOOC605 : MOOC Course

Sr.No	Roll No.	Name of Student	IEM 601n	IEM 603n	MOOC605	SGPA	TC	Failed Courses
			4.00	8.00	4.00			
1	24/IEM/01	NAMAN SACHAN	B+	A+	O	8.75	16	

IEM 601n : Industrial Economics & Management IEM 603n : Minor Project/Research Thesis/Patent OBT601 : Human Nutrition

Sr.No	Roll No.	Name of Student	IEM 601n	IEM 603n	OBT601	SGPA	TC	Failed Courses
			4.00	8.00	4.00			
2	24/IEM/03	AMRISH TRIPATHI	A	A	B+	7.75	16	
3	24/IEM/04	GULSHAN KUMAR SINGH	O	A	A	8.50	16	
4	24/IEM/05	ABHISHEK KUMAR SISODIYA	A+	A+	A+	9.00	16	
5	24/IEM/06	SUNNY SOREN	A	A	B+	7.75	16	
6	24/IEM/07	PRIYATOSH BHARDWAJ	B+	A	B+	7.50	16	
7	24/IEM/08	NGAYOSING A SHIMRAY	A	B+	A	7.50	16	
8	24/IEM/09	SANTOSH KISKU	A	O	A	9.00	16	