Priyatosh Bhardwaj

PB THESIS N3

Document Details

10% Overall Similarity

The combined total of all matches, including overlapping sources, for each database.

Exclusions

- 1 Excluded Source

Match Groups

- **105** Not Cited or Quoted 9%
  Matches with neither in-text citation nor quotation marks
- **15** Missing Quotations 1%
  Matches that are still very similar to source material
- **1** Missing Citation 0%
  Matches that have quotation marks, but no in-text citation
- **1** Cited and Quoted 0%
  Matches with in-text citation present, but no quotation marks

Top Sources

7% Internet sources
4% Publications
7% Submitted works (Student Papers)

Integrity Flags

0 Integrity Flags for Review

Our system's algorithms look deeply at a document for any inconsistencies that would set it apart from a normal submission. If we notice something strange, we flag it for you to review.

A Flag is not necessarily an indicator of a problem. However, we'd recommend you focus your attention there for further review.

Match Groups

- **105** Not Cited or Quoted 9%
  Matches with neither in-text citation nor quotation marks
- **15** Missing Quotations 1%
  Matches that are still very similar to source material
- **1** Missing Citation 0%
  Matches that have quotation marks, but no in-text citation
- **1** Cited and Quoted 0%
  Matches with in-text citation present, but no quotation marks

Top Sources

7% Internet sources
4% Publications
7% Submitted works (Student Papers)

Top Sources

The sources with the highest number of matches within the submission. Overlapping sources will not be displayed.

1	Internet	journal.econworld.org	2%
2	Internet	www.mdpi.com	2%
3	Publication	Thiyagarajan, Senthilkumar. "Building Resilient Supply Chains Through Supply Ch...	<1%
4	Student papers	University of Portsmouth on 2024-05-13	<1%
5	Internet	link.springer.com	<1%
6	Student papers	Adama Science and Technology University on 2025-05-24	<1%
7	Internet	investor-relations.lufthansagroup.com	<1%
8	Student papers	University of Portsmouth on 2023-05-12	<1%
9	Internet	grdspublishing.org	<1%
10	Publication	Kateryna Lysenko-Ryba, Sabina Kauf. "Sustainable Supply Chains in the Digital Ag...	<1%

11 Publication
Lydia Bals, Wendy Tate. "Implementing Triple Bottom Line Sustainability into Glo... <1%

12 Student papers
University of Portsmouth on 2024-05-09 <1%

13 Internet
hull-repository.worktribe.com <1%

14 Internet
discovery.ucl.ac.uk <1%

15 Publication
Dipak Saha, Mrinal Kanti Das, Sunil Sahadev, Rabin Mazumder, Soumya Mukherje... <1%

16 Publication
Nishtha Agarwal, Nitin Seth, Ashish Agarwal. "Selecting Capabilities to Mitigate S... <1%

17 Internet
spectrum.library.concordia.ca <1%

18 Publication
Asian Journal on Quality, Volume 12, Issue 1 (2012-08-06) <1%

19 Student papers
The University of Manchester on 2010-09-06 <1%

20 Student papers
University of Durham on 2010-06-18 <1%

21 Internet
eduvest.greenvest.co.id <1%

22 Internet
www.duo.uio.no <1%

23 Student papers
College of Engineering, Pune on 2021-02-10 <1%

24 Internet
umpir.ump.edu.my <1%

25 Student papers

University of Sunderland on 2023-01-23 <1%

26 Student papers

An-Najah National University on 2014-12-04 <1%

27 Publication

Elham Kakaei, Cesare Zanasi, Cosimo Rota. "Analysis of the mutual influence of s... <1%

28 Student papers

Ghana Technology University College on 2014-04-30 <1%

29 Internet

core.ac.uk <1%

30 Internet

elibrary.pcu.edu.ph:9000 <1%

31 Internet

studenttheses.cbs.dk <1%

32 Student papers

Albukhary International University on 2024-07-01 <1%

33 Student papers

Robert Kennedy College on 2026-06-09 <1%

34 Internet

archive.org <1%

35 Internet

ideas.repec.org <1%

36 Internet

m.growingscience.com <1%

37 Internet

www.researchgate.net <1%

38 Internet

www.sid.ir <1%

39 Internet

www.theses.fr <1%

40 Student papers

Napier University on 2016-04-06 <1%

41 Publication

Prashant Jain, Dhanraj P. Tambuskar, S. S. Vaibhav. "Is the Implementation of Big... <1%

42 Student papers

Rijksuniversiteit Groningen - Tii on 2026-04-16 <1%

43 Publication

Zhihua Chen, Xinguo Ming, Xianyu Zhang, Dao Yin, Zhaohui Sun. "A rough-fuzzy D... <1%

44 Internet

etj.uotechnology.edu.iq <1%

45 Internet

iris.unive.it <1%

46 Internet

mafiadoc.com <1%

47 Internet

www.cleanaway.tw <1%

48 Student papers

Ghana Technology University College on 2014-04-30 <1%

49 Publication

Gyan Prakash, Amandeep Kaur. "AI and Sustainable Transformations", CRC Press,... <1%

50 Student papers

International University Schloss Reichardshausen on 2009-06-30 <1%

51 Publication

Joanna Paliszkiewicz, Ireneusz Dąbrowski, Steven Lorenzet, Angelica Marotta, Qu... <1%

52 Publication

Keon Chul Park, Dong-Hee Shin. "Security assessment framework for IoT service",... <1%

53 Student papers

Laureate Higher Education Group on 2015-12-09 <1%

54 Student papers

University of Bolton on 2019-10-21 <1%

55 Student papers

University of Hull on 2017-08-02 <1%

56 Internet

fs.unm.edu <1%

57 Internet

rsisinternational.org <1%

58 Internet

www.allthingssupplychain.com <1%

59 Internet

www.fancl.jp <1%

60 Student papers

Copenhagen Business School on 2026-02-09 <1%

61 Publication

Dalia Said, Ahmed Foda, Ahmed Abdelhalim, Mustafa Elkhedr. "Performance—Ba... <1%

62 Publication

Journal of Modelling in Management, Volume 8, Issue 1 (2013-03-09) <1%

63 Publication

Lai Xu, Paul de Vrieze. "Digital Twin technologies in enhancing supply chain resili... <1%

64 Publication

Rameshwar Dubey, Angappa Gunasekaran. "The sustainable humanitarian suppl... <1%

65 Publication

Saa'da, Raeda Jamal. "Information Sharing in Humanitarian Supply Chain Manag... <1%

66 Publication

Sachin K. Mangla, Sunil Luthra, Suresh Kumar Jakhar, Anil Kumar, Nripendra P. R... <1%

67 Publication

Senkoto, Nthabiseng. "An Analysis of Critical Risk Factors of Sustainable Supply C... <1%

68 Publication

Studies in Fuzziness and Soft Computing, 2014. <1%

69 Student papers

University of Witwatersrand on 2026-05-29 <1%

70 Student papers

University of Southampton on 2020-09-11 <1%

39

CHAPTER 1

INTRODUCTION

1.1 Background and Motivation

Many of these recent innovations in international supply chains have been driven by a three-decade rise in the implementation of the lean production, just-in-time inventory systems, and global sourcing practices among companies, with a focus on decreasing supply chain costs and increasing response to the marketplace. With such an emphasis on improving market response and cutting costs while still remaining competitive internationally, all of the previous practices worked to create very complex, tender, and vulnerable supply chains. Through several cases of international supply chain disruption we can witness quite clearly the nature of structural vulnerabilities, such as the interruption to the supply of pharmaceuticals, medical equipment, consumer electronics, and food worldwide due to COVID-19, the grounding of Ever Given in March 2021 that blocked global trade worth roughly $9.6 billion per day, the interruptions caused to the supply chains for global grains, energy, and many vital minerals as a result of the conflict between Russia and Ukraine, and a $500 billion revenue deficit caused by interruptions to the supply chains for automobiles and electronic equipment due to the global 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
60 management activities (Teece et al., 1997; Ambulkar et al., 2015).

Meanwhile the expectation of the sustainability has been transformed significantly in the
53 global business. The 17 SDGs under the UN's 2030 agenda for Sustainable Development defined in common a concept of development model that should be social-inclusive and environment-friendly. The relevant Sustainable Development Goals in Supply Chain
7 Management are 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).

10 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).

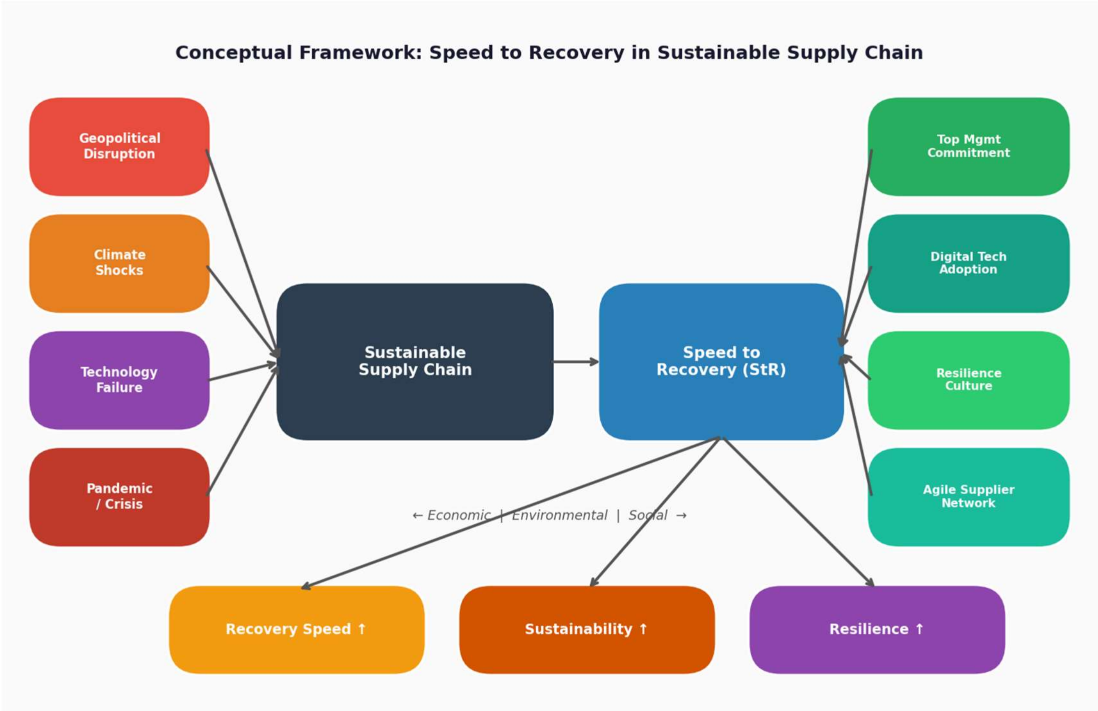


Figure 1.1: Conceptual Framework – Speed to Recovery in Sustainable Supply Chain

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

Based on systematic literature review, 5 mutually related research gaps in the literature have been identified and the present research has sought to fill these gaps:

- 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.

32

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:

4
4

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.

66

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. The TOPSIS methodology could then be used in order to rank all the CSFs providing a complete priority list using their closest distance to the positive ideal solution with the use of weights which would come from the Di values calculated with DEMATEL.

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

The scope of research was defined based on five parameters: Geographical scope- The research is restricted to supply chain practitioners in the industrial scenario of India; Sectoral scope- all the sectors of manufacturing, logistics, retailing, pharmaceutical, automobile, textiles, food & drink, chemicals and humanitarian supply chain; Methodological scope- use of quantitative primary data obtained from structured questionnaires administered to practitioners and analysed using Fuzzy DEMATEL and TOPSIS; Temporal scope- literature review from 2000-2024; Scope of CSFs- four types of CSFs: organizational, strategic, technological and relational. Operational CSFs of the type, relating to a particular inventory strategy or routing algorithm, fall outside the scope.

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

This Dissertation is divided into five chapters. Chapter One shows the context of the Dissertation which covers background, motivation, problem statement, gaps found in the research, research objectives, constraints of the study, research scope and aim of the study. In Chapter Two, a detailed critical analysis of relevant literatures used in the study is presented; it is organized in six individual themes. Chapter Three explains fully all details regarding the methodology that has been used. Chapter Four contains all the empirical results from the study, with a critical analysis of all the results obtained and also DEMATEL causal analysis TOPSIS ranking priorities and sensitivity analysis that were developed by the author. Finally, in Chapter Five, it contains all the main results of the research, contributions for the theory, implications for the management, limitations of the study and scope for further research.

Figure 1.2: Research Methodology Flowchart

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction and Review Methodology

The purpose of this chapter is to critically review the literature relevant to the thesis presented in six major streams: Supply Chain Management; Recovery Speed in Supply Chains; Critical Success Factors in Supply Chain Management; DEMATEL and Fuzzy DEMATEL Methodology; Supply Chain Resilience and Industry 4.0; and Defining the Research Gaps and Theoretical Positioning.

Three prominent databases were searched: Scopus, Web of Science, and Google Scholar. Searches in premier supply chain journals, namely, 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, were also performed to ensure broad literature search. The papers searched are published from year 2000 to 2024, including any prior published papers in year before 2000 that formed fundamental basis for this research.

Search terms were integrated in the form of ('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'). Ninety primary research papers were identified for literature review, and were screened and filtered...

2.2 Sustainable Supply Chain Management

2.2.1 Defining SSCM: The Triple Bottom Line Perspective

The concept of Sustainable Supply Chain Management emerged as a synthesis of two branches of literature. The first one focused on environmental management and the environmental impact of manufacturing activities; the second one focused on the supply chain management concept. Carter and Rogers (2008) made one of the most influential contributions to the understanding of SSCM defining it as the strategic, systematic integration, and continual management of an organization's social, environmental, and economic objectives through effective intra-and inter-organizational process integration, for long-term individual organization and supply chain's economic performance. This definition is also important for encapsulating all three aspects of the triple bottom line and for treating sustainability as an economic long-term goal.

In their 2008 influential study, Seuring & Muller reviewed the contents of 191 journal papers related to SSCM published from 1994-2007. Two separate strategic cluster groups were created based on the two clusters. Cluster group 1: Supplier management for risks and performance. Cluster group 2: Supply chain management for sustainable products. The results of their review show that papers largely considered the environmental, rather than the social aspect, of sustainability. SSCM development from 1990 can be categorized into three phases; Phase I -Green supply chain emerges (1990-2000). Phase II - Integration of social issues in supply chain (2000-2010). Phase III - Interconnected sustainable supply chain with resilience, circular economy, and digital transformation as strategic focus (2010-Present).

Many empirical studies investigated the association between SSCM and organizational performance. For example, Golicic and Smith (2013) reported a meta-analysis including 191 past studies linking environmental supply chain practices and firm financial performance. More specifically relevant to this thesis is the empirical and theoretical framework reported by Fahimnia et al. (2015), who showed that SSCM is related to supply chain resilience. This theoretical and empirical linkage established the rationale of the complementary proposition of sustainability and supply chain resilience, tested empirically 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

Authors (Year)	Focus Area	Methodology	Key Contribution & Finding
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 newest wave of literature on social sustainable supply chain (SSCM) has been investigating the impact of digital transformation (or often described as Industry 4.0) on the sustainability performance. Gu et al. (2021) revealed that, by implementing Industry 4.0 technology, the information asymmetry problem, which restricts sustainability

16 performance, as well as the supply chain disruptions could be overcome by information technology significantly. Digital platforms can help sustainability auditing in suppliers' supply chains; provide products' carbon footprint in their supply chains; monitor the wastes in real-time which fulfill reporting requirement of sustainability and provide information to detect disruption and respond to it rapidly.

4 2.2.2 Circular Economy and Supply Chain Resilience

By building multiple sources of supply for critical material through the practice of CE practices such as CLSC,RL capability, and material reuse systems, the risk for supply chain uncertainty is reduced for the CE oriented organizations. The more that an organization is able to achieve closed loop supply chain and reverse logistics capability, the more supply options are available when critical material are sourced, so this practices
8 is positively correlated with supply chain resilience and reduces the time and scale of supply interruption for critical material (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

12 Speed to recovery (StR) became a defined research area because of investigation of the literature of supply chain resilience in general (Sheffi and Rice, 2005). Sheffi and Rice
4 (2005) establish a new significant perspective on resilience (in terms of supply chain performance) in the development of supply chain resilience, it is called the "resilience curve" which describes the performance of supply chain along time axis from the point of disruption happened to the moment that performance degrades to the new stable level and each phase above can be perceived on the chart where the speed of the recovery phase/trajectory is slope of the recovery trajectory.

16 Ponomarov and Holcomb (2009) define supply chain resilience as "a capability to anticipate risks, response to disturbances, and to recover from the disturbances at a predetermined degree of connectedness and control on structure and functionality". The three consecutive periods of resilience are preparation, response and recovery, where the measure of performance concerning recovery is defined by StR (supply chain recovery).

55

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
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 originally developed through qualitative research by Sheffi and Rice (2005). Initially StR was measured by single-item surveys. The measure was later improved and developed into a multi-item StR measure by Ambulkar et al. (2015). Recent measures of StR have taken a perspective of observable supply chain metrics. A simulation measure of StR was developed by Ivanov (2020) through a comparison of performance during a disruption period to the performance before the disruption. Hohenstein et al. (2015) determined three dimensions for measuring StR as recovery time, recovery completeness and recovery cost..

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

The CSFs of the StR can also be further understood with the information present in the humanitarian supply chain management literature, since humanitarian supply chains inherently have their structures to enable rapid recovery of performance. Tatham and Spens (2011) list key influencing factors which are critical to achieve rapid response to humanitarian emergencies as pre-positioning of relief goods, good local networks with the agencies, standard operating procedures, developed training programs, etc. Also Day

(2014) identified the role of newly formed structures and inter-agencies interaction during the response. Additionally, Yadav and Sharma (2016) analyzed critical success factors for humanitarian supply chain performance in India using Fuzzy DEMATEL and identified two clusters, IT infrastructure and partnership between agencies had causal grouping, which is consistence with the ones discussed in this study.

2.5 DEMATEL and Fuzzy DEMATEL Methodology

2.5.1 Origins and Theoretical Foundations

5 In the 1970's, Science and Human Affairs Program at the Battelle Memorial Institute's Geneva Research Center, DEMATEL was developed as an innovative approach toward gaining a richer and more productive knowledge of human relationships in complex environments due to science and technology. The DEMATEL approach uses Graph Theory, Matrix Algebra and Causal relationships among System Elements via the use of directed graphs and matrix operations. Two main pillars are used in the Graph Theory-based DEMATEL approach: depicting causal relationships among system elements using directed graphs, and calculating total causal effect from each factor on other elements using matrix operations.

What is most impressive about DEMATEL approach and makes it special is the capability it provides in distinguishing two types of causalities, "cause-related" and "effect-related", 61 among factors within a multifactor system. The two components (Di: total influence that 41 factor i has on all other factors and Ri: total Influence received by factor i from all other factors), allow the factors to be categorized into these two types and so the management can decide where to direct its effort in order to obtain maximal systemic impact with minimal 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.

10

2.6 Industry 4.0 and Supply Chain Resilience

2.6.1 The Industry 4.0 Paradigm

40 Industry 4.0, also know as the Fourth Industrial Revolution is described as the technological revolution of the world economy, for reengineering of operations with regard to manufacturing products, as well as distribution and supply chains. A concept that integrates the application of IoT, Cloud computing, Big Data, Artificial Intelligence, Blockchain, Additive manufacturing and Digital Twin within an overarching framework of engineering design in which a supply chain is organized (Schwab, 2016). The word industry 4.0 came to be in 2011, in the Hannover Messe Trade Fair, and now it has become the paradigm that represents today's supply chain management system technologies.

In terms of SCM perspective, I4.0 technologies are making differences in how supply chains are designed, built and operated, shifting them from reactive, information-poorer operations to proactive, information-rich, digital driven supply chain ecosystems linked through technology. The multi-tier visibility by IoT, the artificial intelligence based demand sensing and forecasting, the verification system for the suppliers using blockchain, and the digital twin technology for simulation are among the expected I4.0 characteristics with major influence on SCM.

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)
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)

I4.0 Technology	Primary Application in SC Management	Specific Impact on StR / Recovery Speed	Key Academic Reference
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.

On the other hand, according to Belhadi et al. (2021), the adoption of I4.0 may lead to a simultaneously generation of new vulnerabilities by developing new set of cyber security vulnerabilities and by relying on digital infrastructure. Thus, organizations will need to take care of the adoption of I4.0 technologies and of investments in cybersecurity resilience so that their organization resilience can be enhanced. In other words, the improvement of the organization resilience via I4.0 adoption will create new emphasis on resilience through cybersecurity resilience as a new critical success factor not presented in the list of critical success factors studied in this article, and it is the direction of the 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.

31

CHAPTER 3

METHODOLOGY

3.1 Research Philosophy and Design

This paper follows the research philosophy of pragmatism, which supports an applied methodology toward appraising research on the basis of its problem-solving capabilities. For this research, pragmatism fits well with the application of MCDM in a supply chain management study where the desired output is the establishment of decision relevant results. Pragmatism permits the application of the interpretation power offered by language judgments of the experts with the rigorousness provided by the quantification calculations of a matrix to form a research methodology.

15

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.

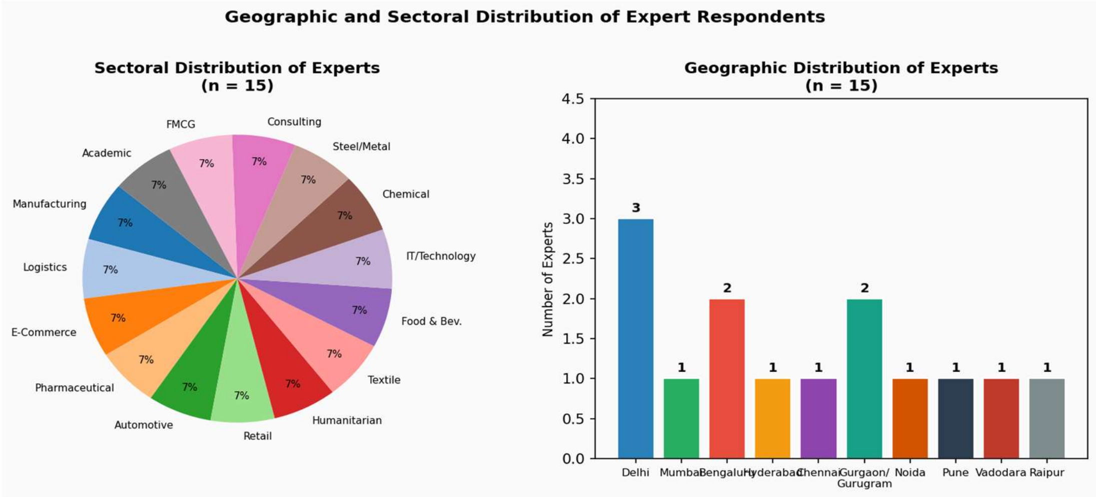


Figure 3.2: Geographic and Sectoral Distribution of Expert Respondents

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)..

2

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

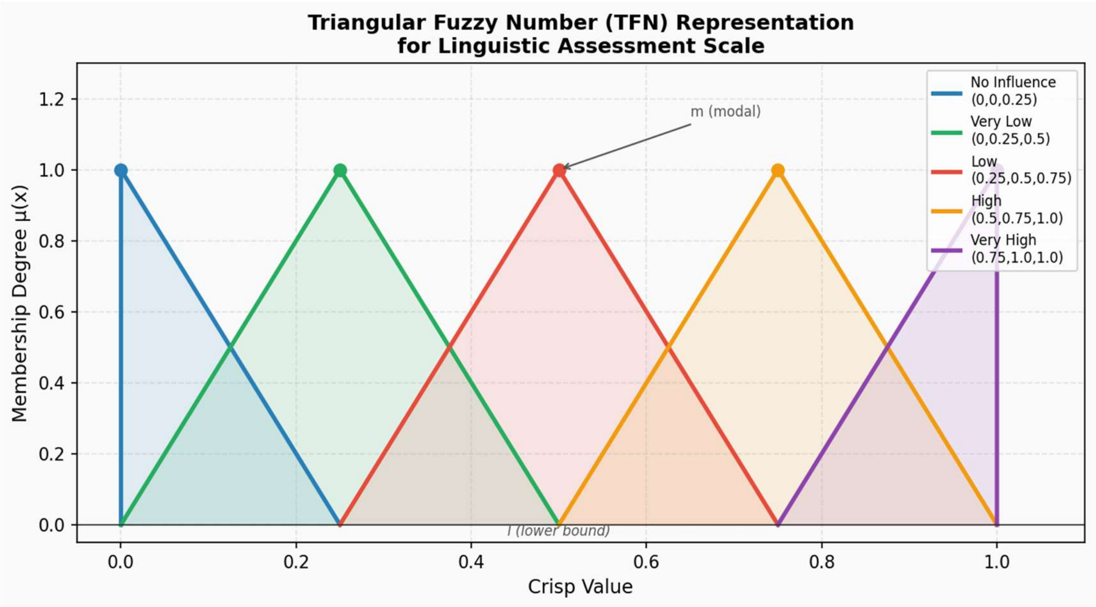


Figure 3.3: Triangular Fuzzy Number Representation for all Five Linguistic Levels

3.5 Phase 2: Fuzzy DEMATEL Analysis

52 ### 3.5.1 Step 1 – Construct Individual Fuzzy Direct Relation Matrices

9 The experts' 15 pairwise evaluations were converted into corresponding triangular fuzzy
6 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
2 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.

44 ### 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 $\tilde{\bar{z}}ij$, 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 $zij = (\bar{l}ij + \bar{m}ij + \bar{u}ij) / 3$.

23 ### 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.
68 Therefore, let $X = Z / \max(1 \leq i \leq n)(\Sigma j\ zij)$. By normalizing the direct relation matrix, all elements of X lie between 0 and 1, and also ensures that the maximum amount of influence
4 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.

5 ### 3.5.5 Step 5 – Compute Total Relation Matrix

56 17 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).

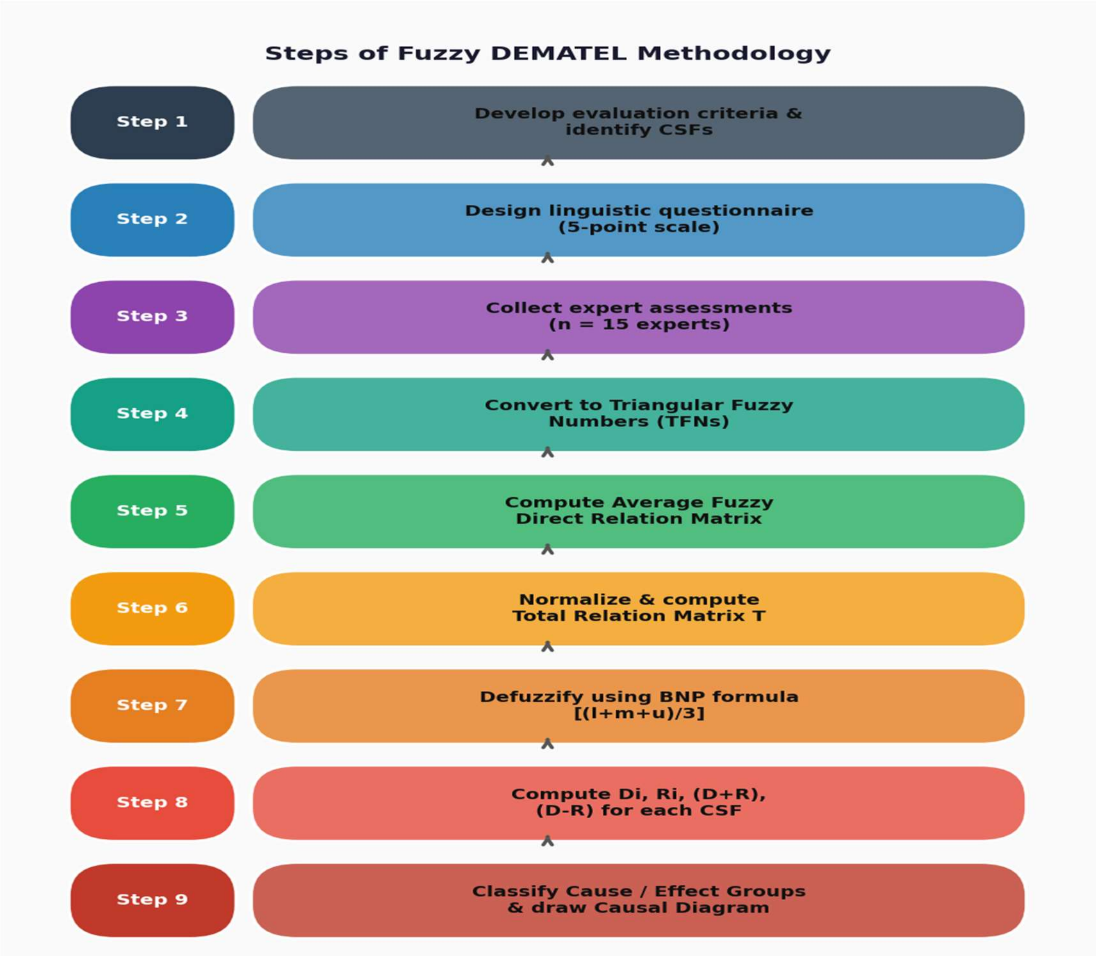


Figure 3.4: Steps of the Fuzzy DEMATEL Methodology

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.

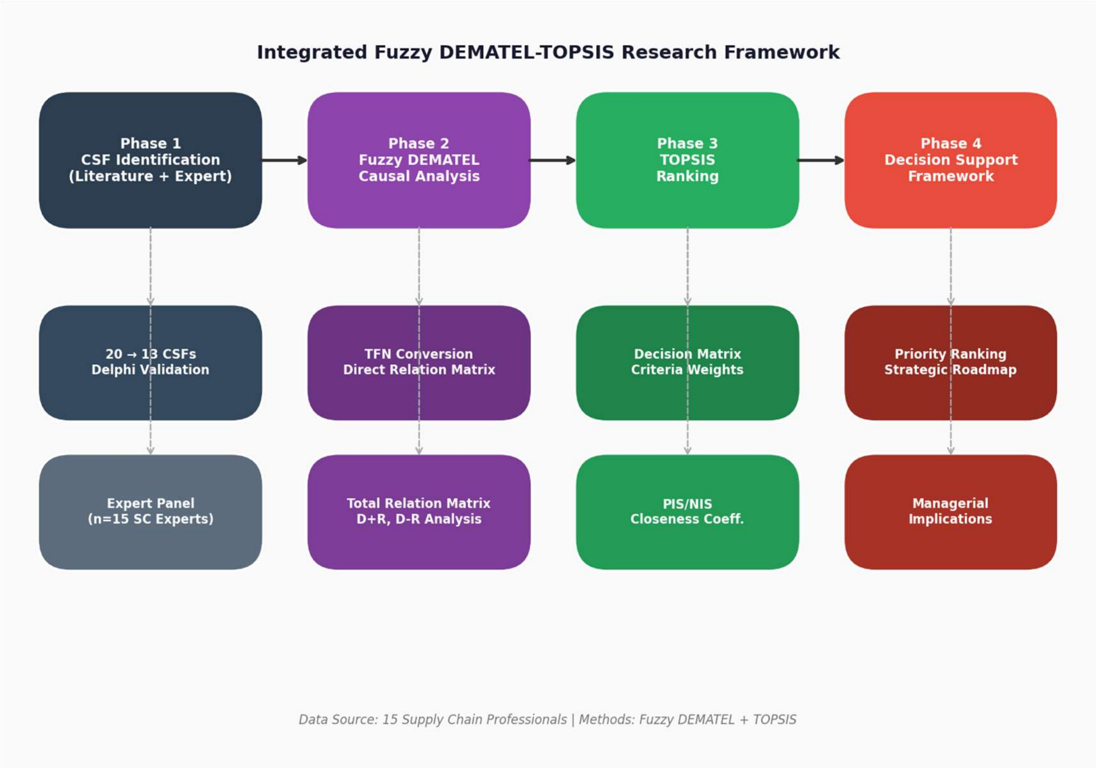


Figure 3.1: Integrated Fuzzy DEMATEL-TOPSIS Research Framework

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..

29

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Phase 1 Results: CSF Identification and Validation

The initial pool of 47 CSFs was identified through the systematic literature review, and refined into 20 key CSFs by semantic similarity. This was followed by two Delphi iterations involving a 15-expert panel, and results are presented in Table 4.1 as a finalized 13 validated CSFs. The removal rationale is: Complexity of Supply Chain Network, it is downstream and cannot be managed, customer demand visibility; Standards on worker safety were a prerequisite, they were removed as there is always a minimum standard; Insurance & financial hedging instruments are both considered tools, therefore grouped as one; supplier geographic diversification became a part of agile supplier network; ESG Reporting maturity was categorized under environmental regulatory compliance; Crisis communication protocol was added to the Cross-functional collaboration. Average relevance scoring by the experts (out of 5) for the retention of the 13 CSFs is 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 This is

2

CSF ID	Critical Success Factor	Operational Definition & Key Literature Support
		identified and measured within a budget that has been specified and accounted for; incorporating measures of supply chain resilience into the KPI reporting that is communicated to the Executive team; and sending the message through the supply chain organization that supply chain resilience is one of the Executive level priorities. (Carter & Rogers, 2008; Chin et al., 2012)
CSF3	Digital Technology Adoption (I4.0)	The level of technological integration within the supply chain with reference to Industry 4.0 systems and functionalities like: IoT connected multi-tier visibility platforms, AI-based demand sensing and recovery planning, blockchain technology for supplier traceability and, digital twin simulation capacities (Gu et al., 2021; Ivanov & Dolgui, 2021; Belhadi et al., 2021).
CSF4	Agile Supplier Network	The ability to rapidly reconfigure suppliers after disruption in a timely fashion, considering geographical and sector diversity of supply sources, having pre-approved backup suppliers, establishing collaborative and flexible relationships with key suppliers, and adopting a cooperative approach in 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 (accurate and timely information of SC disruption from multiple levels) that facilitates an earlier identification of SC disruption, rapid situation appraisal and decision making/response (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 level at which supply chain partners share reliable, on time and decision relevant information (e.g. Demand forecast, inventory data, production plans, supply chain disruptions and recovery efforts alert) so information asymmetry across supply chains (between supply chain partners) reduced (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	Pre-active engagement in relation to supply chain environmental regulation (which covers infrastructure for anticipating compliance, regulator interaction, environmental management systems (ISO 14001), involvement in industry-based environmental standards etc.) (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 level of maturity of an organization's closed loop supply chain design, reverse logistics operations, processes that make use of wastes and their integration into secondary supply chains provides a basis to simultaneously lower reliance on the vulnerable primary supply chains and establish diverse redundancies for primary supply chains. (Zhu et al, 2019; Govindan et al, 2021)
CSF12	Risk Assessment & Monitoring	The breadth and day-to-day uniformity in the execution of the systematic processes to identify, evaluate and monitor supply chain risks which encompasses mapping each level of the supply chain, implementing tools for risk heat mapping, utilizing a dashboard for monitoring the key risk indicators, and running periodic simulations of disturbances in a scenario. (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

Taking the element-wise arithmetic mean of these fifteen individual (13 by 13) expert fuzzy direct relation matrices, the average fuzzy direct relation matrix. The three stages of total relation matrix T = X(I-X)-1 which demonstrates the direct and/or indirect cause-effect relationship for all 13 CSFs throughout the various routes are shown in table 4.2-4.4.

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 lists out the computed Di, Ri, Di + Ri, and Di Ri values from the total relation matrix for all the 13 CSFs in order of their importance. Table 4.6 shows the classification of CSFs into causes and effects with its managerial implications.

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

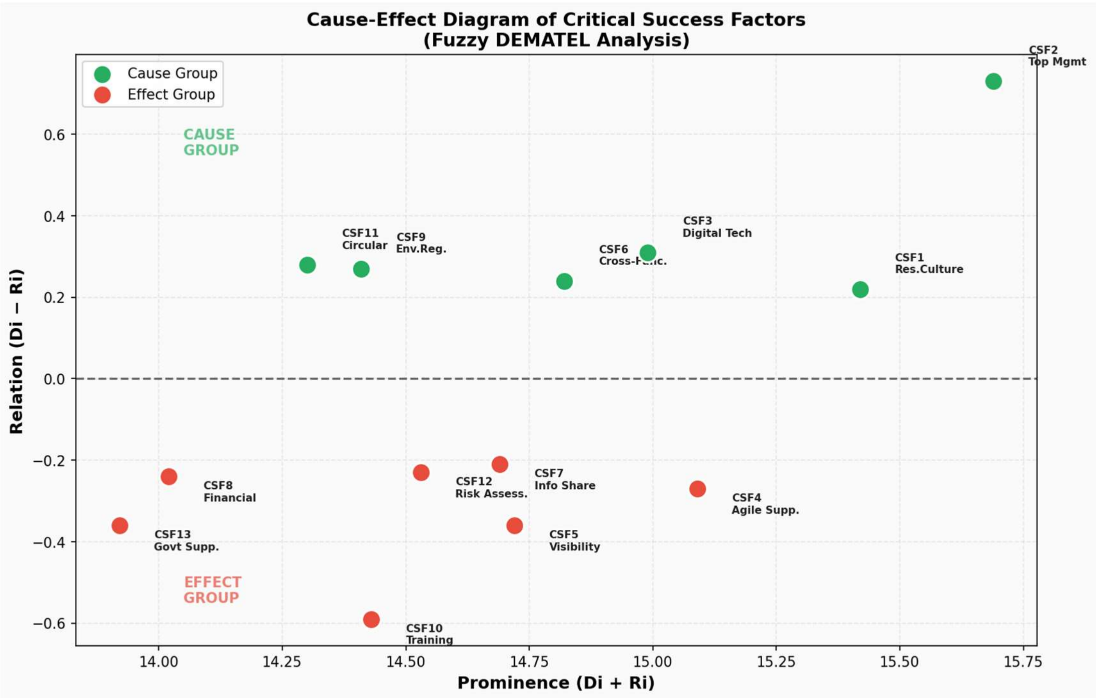
Table 4.6: Classification of CSFs into Cause and Effect Groups with Managerial Interpretation

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.



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

25 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.

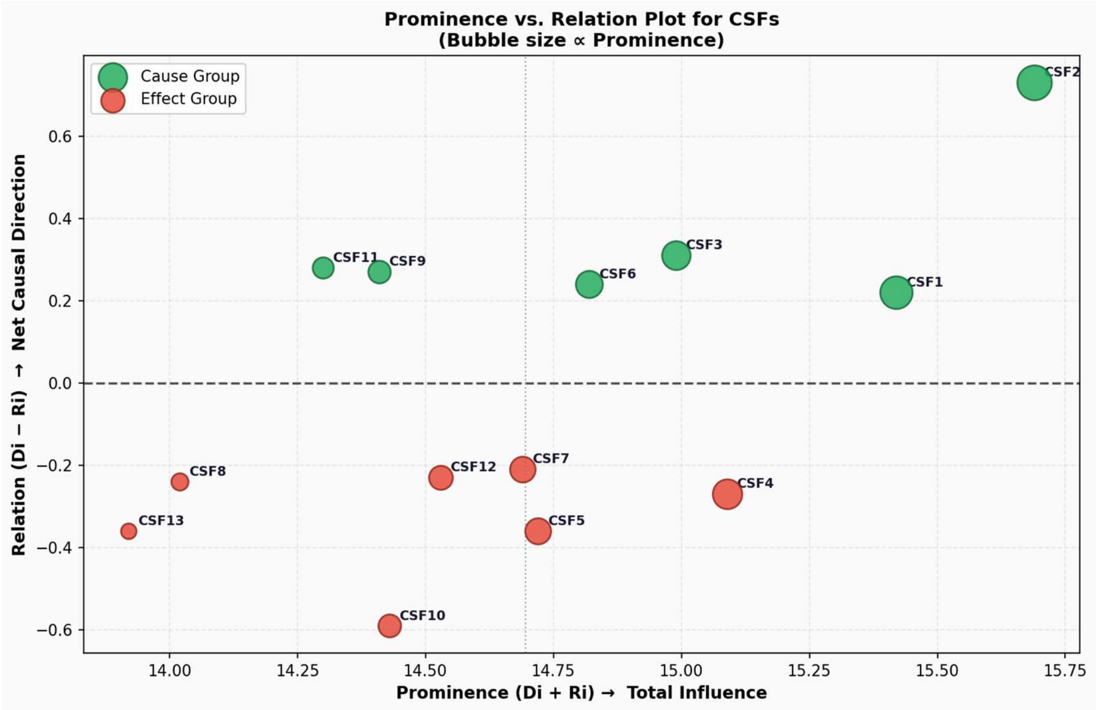


Figure 4.2: Prominence vs. Relation Bubble Plot for CSFs

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.

5

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

2

34

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

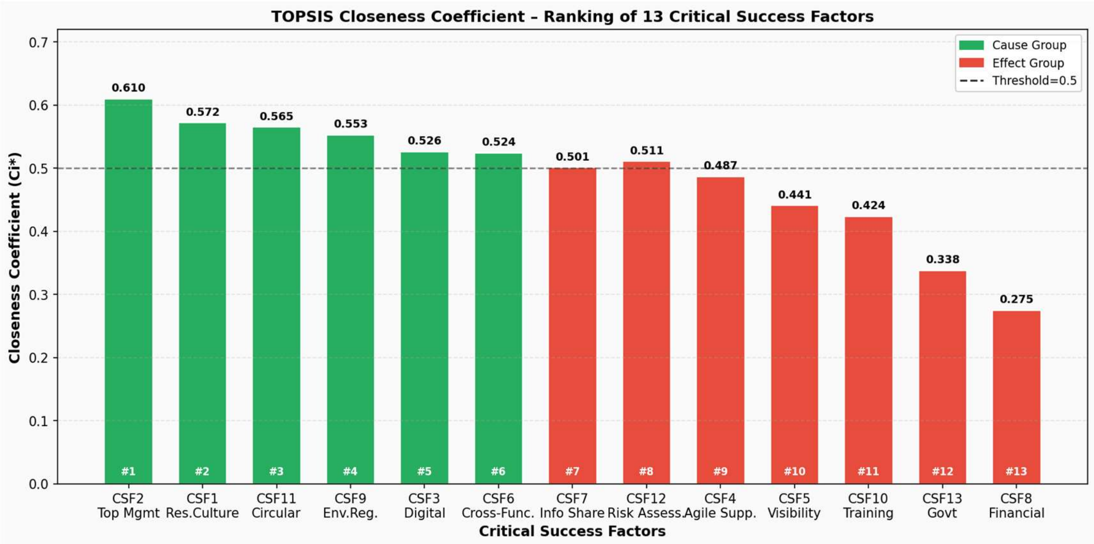


Figure 4.3: TOPSIS Closeness Coefficient Bar Chart – Ranking of all 13 Critical Success Factors

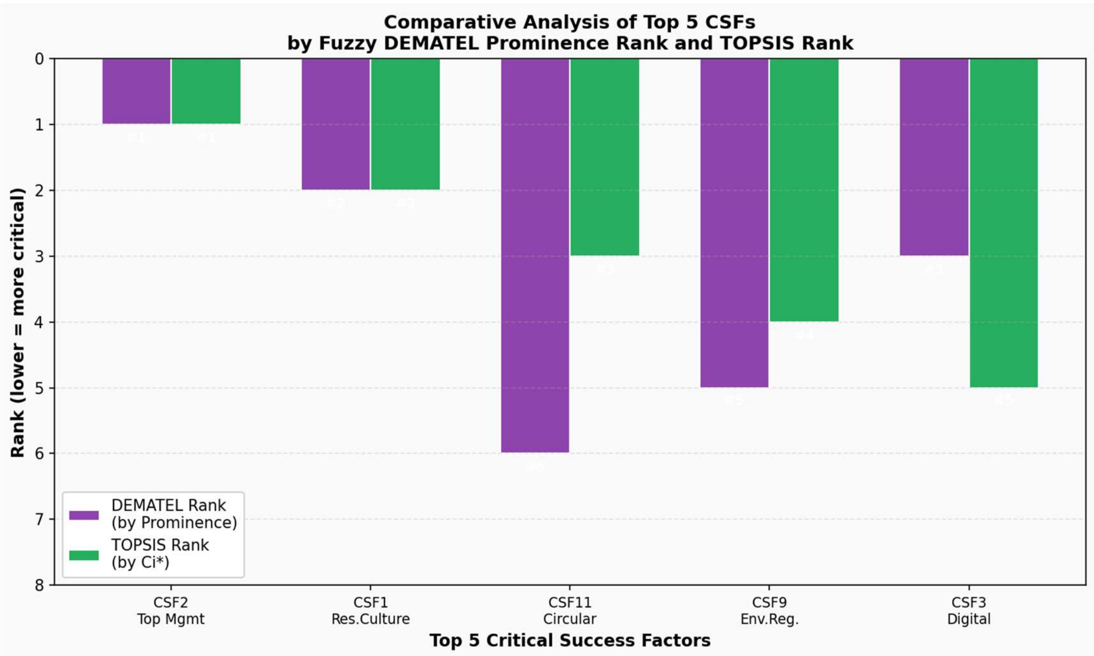


Figure 4.4: Comparative Analysis of Top 5 CSFs by Fuzzy DEMATEL and TOPSIS Rankings

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

18 The top two critical success factors (CSFs), Top Management Commitment and Organizational Resilience Culture appear to be totally insensitive to the differing CSF weighting schemes (ranked first and second in all four scenarios), according to the sensitivity analysis results. CSF8 (Financial Resource Availability) remained ranked last in all four scenarios, therefore the result is not dependent on any of the four weighting schemes applied to the calculation of CSF ranks. There was a slight change in ranking for

CSFs 11 and 9, those focused on sustainability, from sustainability-oriented to recovery-oriented scenarios but the rankings for CSFs 11 and 9 remained in the top four ranked CSFs in both equal and baseline weighted scenarios. A noticeable shift from 8th place to 4th place occurred when CSF12 (Risk Assessment and Monitoring) was considered with respect to the recovery-oriented weighting scheme.

4.6 Discussion and Comparison with Existing Literature

These findings support the earlier studies, and add extra insight to the subject area as well. The results of this research state that DEMATEL and TOPSIS analysis overwhelmingly prefer Top Management Commitment (CSF) as the critical success factor. This agrees with Chin et al., 2012, Green Supply Chain Management and Rajesh & Ravi, 2015, Supply Chain Resilience studies which claimed similar findings. With Top Management Commitment (the basis of CSF) continuously selected as a crucial factor to all supply chain management elements, it shows that Top Management Commitment is a constant factor which needs to be satisfied prior to the initiation of any supply chain changes.

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.

30

CHAPTER 5

CONCLUSIONS, IMPLICATIONS, AND FUTURE DIRECTIONS

5.1 Summary of the Research

The research reviewed herein focuses on identifying critical success factors for
51 successfully implementing speed of recovery in the context of sustainable supply chain development. The research was driven by the ever-present need for organizations to
10 implement both supply chain resilience and supply chain sustainability simultaneously as key drivers to adapt to ever more frequent supply chain disruptions. The research identified a gap in existing literature and created an integrated framework of critical success factors empirically tested and validated at the convergence of speed of recovery and sustainable supply chain management.

The research process used an integrated four-step methodology: first a systematic literature review and two rounds of Delphi validation were conducted to extract and refine the list of 13 critical success factors from an initial 47 candidate factors; second a fuzzy-DEMATEL analysis of the linguistic inputs of 15 supply chain professionals was completed to determine interdependencies between the factors and categorize them as drivers or outcomes; third the criteria weights derived from the DEMATEL analysis were combined with TOPSIS analysis to form an integrated prioritized ranking; finally the validity of the outcome was verified using sensitivity and comparison with related literature..

The data gathered in this study was used to draw three major conclusions: (1) Top Management Commitment (CSF2) emerged as the strongest CSF throughout all data analyses of the data which is considered as the systemic driving factor for establishing the StR capability, (2) circular economy measures (CSF11) and environmental regulations (CSF9) entered into the causative linkage, becoming one of the four strong CSFs in which investments in sustainability constitute structural enablers for the StR, and (3) although Financial Resources were conventionally seen as significant driving factor of rapid recovery, this study has provided with evidence indicating that financial resources are the necessary enabling factor rather than sufficient factor to establish StR.

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)

3

35 The first theoretical contribution is the creation of an combined speed to recovery - sustainability (sustainable supply chain management) - and multi-criteria decision making (MCDM) empirically validation framework. These developing/additional findings are aiming to fill the gap mentioned in the previous section 1.3 and to provide an excellent theoretical and empirical base to follow researchers.

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
9 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

59

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 origin of the development of all future critical success factors will be the Tier 1 investments in top management commitment and organizational resilience culture, representing the foundation block of all future development. A lacking of leadership commitment will make any resilience investment program seem a compliance, not a transformational based effort. Leaders must ensure that supply chain resilience and sustainability issues are given strategic priority backed with significant investment and ideally (even board level monitoring).

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

15 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

There are several limitations in this study that must be taken into consideration when looking at the 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 research currently explored opens up a number of fruitful directions for further investigation:

- 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.

46

- 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.

69

- 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

67 In conclusion, this study investigates a critical, paramount research gap in the supply chain management literature; it is the development and empirical validation of a critical success factor framework for the implementation of sustainable supply chain Speed to Recovery (StR) by means of an integrated empirical approach. This study generates a causally ordered and ranked CSF framework contributing to theory and providing a decision support system to 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.

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	