ABSTRACT

Recent semiconductor supply chain (SSC) disruptions and variability increases for demand multiples orders of merit over past decades, along with fundamental uncertainties from around the world, have become of critical interest. To ensure the long-term viability of SSCs, a better understanding of the risk factors and structural dynamics that can influence their performance and resilience is needed. The elements of SSC viability were explored through expert insights gathered from two Expert Committees, one of which consists of professionals from academia and the second of which consists of professionals from the industry. Finally, the analysis illuminates the intricacies of the drivers enhancing supply chain resilience, whereby some drivers play as foundational enablers while some other drivers play a role as outcome drivers. Focus is placed on the importance of strategic partnerships to increase flexibility, lower vulnerabilities, and enhance continuity facing disruptions. Implications of the findings lay the basis for a systemic perspective of the SSC dynamic, providing vital insights to the stakeholders involved in designing the robust, future-ready supply chains. In adopting the TISM framework to study how SSC management affects the manufacturing supply network of high-tech firms, this work contributes to the growing discussion on SSC management by offering insights which can assist in policy decisions, strategic operations, and future research on high-tech manufacturing supply network systems.

Keywords: *Semiconductor Supply Chain (SSC); Viable Supply Chain (VSC); Risk Factors; TISM; Expert Committee; Strategic Partnerships; Supply Chain Resilience;*

LIST OF SYMBOLS AND ABBREVIATIONS

∩	Intersection
A	Antecedent Set
DOAJ	Directory of Open Access Journals
EC	Expert Committee
FRM	Final Reachability Matrix
HMLV	High-Mix Low-Volume
I	Intersection Set
IRM	Initial Reachability Matrix
LMHV	Low-Mix High-Volume
OKRF	Open Knowledge Resilience Framework
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
R	Reachability Set
SCA	Supply Chain Agility
SCIS	Supply Chain Interoperability Standards
SCIS	Supply Chain Interoperability Specification
SDOL	ScienceDirect Online Library
SSC	Semiconductor Supply Chain
SSC	Semiconductor Supply Chain
SSP	Segment Stock Plan
TISM	Total Interpretive Structural Modelling
TSMC	Taiwan Semiconductor Manufacturing Company

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

The semiconductor industry plays a crucial role in the modern technological landscape, serving as the backbone of various sectors including consumer electronics, telecommunications, automotive, aerospace, defense, and healthcare. Semiconductors, also referred to as integrated circuits or microchips, are essential to almost every aspect of modern life. They power smartphones, computers, electric vehicles, medical equipment, and high-end industrial machines, thereby enabling advancements in automation, connectivity, and smart system. Among the manufacturing models, Low-Mix High-Volume (LMHV) is particularly critical for producing standardized semiconductor components at scale, which meet the growing global demand across high-volume application segments.

However, the COVID-19 pandemic starkly exposed the structural vulnerabilities embedded in global semiconductor supply chains. The industry witnessed unprecedented disruptions when supply and demand mismatches occurred simultaneously. While manufacturing facilities across Asia—home to the majority of chip fabrication plants—faced closures and labor shortages, demand for digital devices surged due to remote work, e-learning, and digital transformation across sectors. The automotive industry, which initially reduced chip orders in anticipation of lowered demand, found itself crippled by shortages as recovery outpaced supply expectations. Port congestion, reduced air cargo capacity, and geopolitical tensions further exacerbated the crisis. Compounded by natural disasters and factory fires in key locations like Taiwan and Japan, the semiconductor shortfall became a global issue, affecting production timelines, cost structures, and innovation roadmaps across industries.

This leads us to the core research question: "**How can a viable and resilient supply chain framework be developed for LMHV semiconductor manufacturing by understanding interdependencies among key factors through structured modeling approaches**?" Addressing this question is essential because the world has witnessed how a single chokepoint in semiconductor production can cause ripple effects across global industries—from carmakers halting production lines to medical equipment manufacturers struggling with component delays. As semiconductors remain indispensable to digital transformation and national security alike, strengthening their supply chains becomes not only an economic necessity but also a strategic imperative.

The importance of this research lies in its relevance to both industry and policy. While numerous studies have explored high-mix low-volume (HMLV) or advanced fabrication, limited attention has been given to the Low-Mix High-Volume (LMHV) semiconductor domain, especially from the lens of supply chain viability and resilience. Viability, in this context, refers to the ability of a supply chain to sustain operations while balancing economic, environmental, and social dimensions. Resilience refers to the supply chain's capacity to absorb disruptions, adapt to change, and recover swiftly while maintaining performance. The novelty of this paper lies in framing a strategic model specifically tailored for LMHV semiconductor manufacturing, derived from empirical interdependencies of critical challenges observed during the COVID-19 crisis. Unlike generalized supply chain models, this research focuses on sector-specific dynamics and offers structured insights via modeling techniques (e.g., ISM/TISM), which until now have been underutilized in this domain.

1.2 LITERATURE REVIEW

A literature review was carried out based on the PRISMA on viable supply chain and semiconductor shortages, factors affecting the viability of the semiconductor supply chain. The entire process of this section proceeded after selecting the keywords based on the title. Keywords like Viable Supply Chain (VSC) and Semiconductor Supply Chain (SSC). After identifying the keywords, extensive research was done on databases like Open Access Journals (DOAJ), ScienceDirect (SDOL), Scopus, Emerald Publication, and Google Scholar. These databases were explored, and 2543 articles and 16 additional references were identified, out of which 322 articles were selected. The selected articles were scanned, and only the articles that were directly related to the objectives of the research were followed. The selected articles were then screened to find relevance based on the following criteria,

- Papers that contain any information that supports the aspects of the viability of a supply chain.
- Papers accessing COVID-19 disruptions and semiconductor shortages.

Based on the above screening criteria, the final set incorporated 61 articles in the form of peer-reviewed references.

The 61 articles were reviewed extensively, followed by the data extraction process along with the expert committee members. The data extracted from the articles provided the factors that drive the viability of the supply chain in semiconductor industries. Fig. 1 demonstrates the PRISMA flowchart. The following review of the literature explains the VSC theory and the SSC, ensuing by the gaps in the literature.

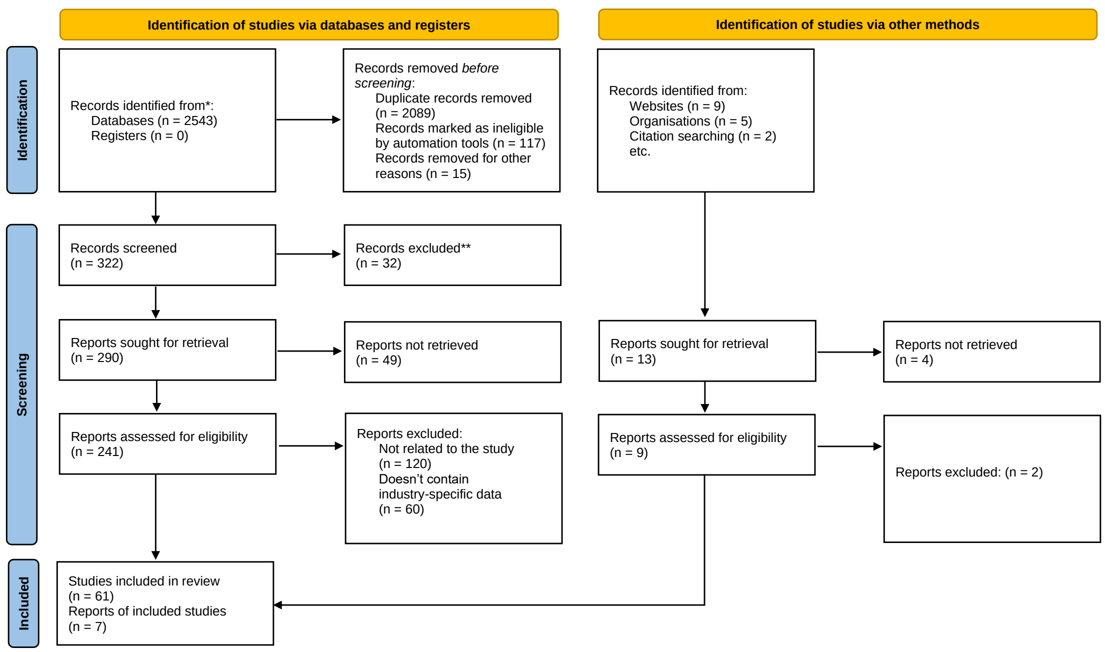

Fig. No. 1.1. PRISMA flowchart.

1.2.1 Viable Supply Chain

A Viable Supply Chain (VSC) stands as an advancement of supply chain management by using resilience alongside sustainability and agility as core principles that surpass traditional lean and efficient systems. The VSC is a network with dynamic adaptability that presents both flexible structure and quick market response together with disruption immunity and recovery abilities. Such adaptive business strategies protect long-term organisation survival because they help businesses maintain alignment with sustainable development goals while providing ongoing supplies of goods. The VSC model chooses structural transitions between alternate configurations while monitoring both internal and external elements that include economic stability as well as geopolitical risks and environmental conditions instead of conventional short-term efficiency models. The Open Knowledge Resilience Framework (OKRF), together with the Supply Chain Interoperability Specification (SCIS), provide platforms that boost VSC success through transparent data exchange and adaptability and enhanced visibility. These frameworks enable supply chains to make instant decisions and seamlessly share information through interoperability, which allows networks to stay operational during different operational hurdles.

1.2.1.1 Agility

Agility in a Viable Supply Chain refers to the fast responsiveness of adapting to market dynamics together with the ability to seize opportunities and preserve operational efficiency. A networked supply chain uses this capability to modify its configuration when it faces changes in customer demands, technology evolutions and preference movements. This can be made possible through real-time tracking and control, often brought about by Industry 4.0 technologies. The connection between agility and legality brings together lean and agile aspects that create both responsive systems and cost-efficient solutions. The Open Knowledge Resilience Framework (OKRF) system executes supply chain decisions more effectively through automated processing because of implementing machine-readable data standards that operate as modular units**.** Through the implementation of open standards, companies gain better collaboration while sharing knowledge through standardised formats, which accelerates their ability to adopt new technologies and trends in the industry. A VSC functions well due to its ability to rapidly change supply chain approaches, which drives better market speed along with shorter lead times and contented customers, thus pushing agility to a most important position. Indeed, the ability to respond rapidly (agility) is more effective than long-term flexibility in reducing the effect of a disruption, and the OKRF data standards promote Supply Chain Agility (SCA) through modularity and composability.

1.2.1.2 Resilience

The fundamental aspect of a Viable Supply Chain involves resilience because it enables flexible shock absorption accompanied by operational restoration alongside long-term operational sustainability. The effective protection of a supply chain depends on its ability to implement risk management plans and its use of different suppliers and product stockpiles, along with emergency response documents. These strategies help maintain continuous business operations during interruptions. The Open Knowledge Resilience Framework (OKRF) serves as an essential tool to boost resilience capabilities through its capabilities to conduct pre-emptive risk evaluations while delivering standardised disruption management systems. The Supply Chain Interoperability Specification (SCIS) platform enables swift disaster recovery operations by enabling users to find backup suppliers and redistribute resources when supply chain disruption occurs. A VSC becomes more resilient through its deployment of redundancy, together with flexibility and technological adaptability, which enables effective disruption management and success in ever-changing industries.

1.2.1.3 Sustainability

The Viable Supply Chain requires sustainability as its integral foundation to ensure operational fulfilment of environmental, economic, and social sustainability objectives. A VSC operates to keep supply chains thriving over time while lowering both environmental effects and upholding ethical sourcing standards and resource management excellence. Through its integration of circular economy principles, the Supply Chain Interoperability Specification (SCIS) platform and the Open Knowledge Resilience Framework (OKRF) help businesses minimize waste generation while maximizing material efficiency. The construction of recycling programs and resource repurposing and reverse logistics systems becomes possible through these frameworks to sustain both product and material utilization periods. Social sustainability is promoted by businesses that ensure fair labour practices alongside transparent supply chain operations and community engagement for ethical business conduct. Companies that use efficient energy consumption alongside localized supply chains and optimized production sequences achieve enhanced economic sustainability. The balanced integration of social, economic and environmental sustainability pillars by VSCs helps to lower their exposure to regulatory pressure and public accountability concerns as well as market instability, which leads to stronger, resilient, sustainable global supply networks.

1.2.2 Semiconductor Supply Chain

The semiconductor supply chain is a complex web of global industrial activities that begins with the extraction of raw materials, progresses through the intricate creation of semiconductor chips, and culminates in their integration into diverse products. The initial stage involves the extraction of raw silicon, followed by rigorous purification processes during wafer manufacturing. Subsequently, integrated circuits are realised through sophisticated photolithographic techniques. The semiconductor market is broadly divided into two main categories: foundries, which possess their own manufacturing and production facilities, and fabless companies, which primarily focus on the design and development of semiconductor products without owning fabrication plants. Key players in the foundry segment include TSMC, Intel, and Samsung. Maintaining semiconductor manufacturing is a challenging endeavour due to the requirement of highly sophisticated equipment and geographically dispersed supply chains that are susceptible to geopolitical influences. The automotive industry constitutes a smaller market segment for semiconductors compared to the consumer electronics sector. Consequently, during periods of high demand and limited supply, the automotive industry often receives lower priority in chip allocations. This prioritisation issue, coupled with extended production lead times in semiconductor manufacturing and the substantial financial investments required for fabrication facilities, underscores the critical importance of semiconductor supply stability for the automotive sector, necessitating strategic supply chain approaches. The recent semiconductor shortage, significantly impacting the automotive industry, has been attributed to a combination of factors, including the COVID-19 pandemic, subsequent demand recovery, supply disruptions (such as factory fires and natural disasters), the complexity of automotive supply chains, realignment of chip manufacturing capacities towards more profitable sectors like consumer electronics, and geopolitical risks including trade tensions. The shortage has led to production line closures and reduced output for numerous automotive manufacturers. Addressing the semiconductor supply challenges requires strengthening international cooperation, increasing the localisation rate of chip production in some regions, and fostering closer collaboration and communication between automotive manufacturers and semiconductor suppliers. Long-term strategies for the automotive industry include developing stronger technology roadmaps, improving demand planning, and considering strategic investments and direct sourcing to enhance supply chain resilience.

1.2.2.1 Semiconductor Shortages

The semiconductor shortages experienced by the world in 2020 evolved from three main factors, which included both pandemic-related market changes and industry supply chain issues along with permanent industry elements. When automotive manufacturers decreased their orders at the beginning of the pandemic, semiconductor foundries chose to shift their production capacity to more profitable consumer electronics production. After demand for vehicles returned strong, the automotive industry experienced an intolerable gap between real and projected demand because semiconductor-producing plants endured factory shutdowns, natural disasters and geopolitical tensions. Semiconductor manufacturing leads have reached six months, and this has caused additional delays in recovery processes. Automotive companies started to purchase an excessive number of chips, leading to amplified volatility through the bullwhip effect. International supply chains, along with vital raw material sources, including neon gas and palladium, made the semiconductor industry highly exposed to political disturbances in global markets.

1.2.2.2 Low-Volume, High-Mix (LVHM) Manufacturing

LVHM manufacturing faces distinct supply chain challenges because its products have many custom variations and unpredictable market requirements. The production requirements of LVHM operations revolve around serving specific niche markets because customers request customised product configurations that increase manufacturing complexity. The LVHM manufacturing industry faces supply chain challenges because of restricted supplier ordering capabilities, delayed procurement durations and higher exposure to outside influences. The unpredictability in customised orders finds no resolution with traditional forecasting methods, so LVHM companies need to adopt the Segment Stock Plan (SSP) as their alternative forecasting approach. SSP manufacturers designate components as either stocked or ordered, and then they use dynamic inventory planning methods alongside advanced supply chain visibility. LVHM manufacturers can deliver improved delivery results through the development of advanced part segmentation methods, stocking calculations and adaptive planning methods. The combination of data-driven choices, digital supply chain tools, and supplier collaboration activities builds LVHM operations' flexibility along with responsive features. Solution-driven efforts aimed at these difficulties bring about enhanced operational efficiency and better costs alongside improved service levels inside specialised manufacturing circumstances. Your description of the supply chain challenges in LVHM manufacturing aligns closely with the difficulties faced by low-volume, high-mix industrial companies, as highlighted by. These companies often struggle to obtain the necessary parts for production due to the small quantities required and suppliers prioritising larger customers. The increasing demand for customisation further complicates efficient supply chain management in such environments.

1.3 KNOWLEDGE GAINED FROM LITERATURE

In this learning journey, I became fluent with Viable Supply Chains (VSC), not only what is it but how it is different from traditional Lean models with nothing but agility, resilience, and sustainability as the way to long term viability. Agility helped me to identify the critical role it plays in real-time responsiveness and resilience, which is effective shock absorption and recovery strategies, both of which are vital for keeping the supply chain in the continuity cycle when it is disrupted. Furthermore, I learned about the integration of sustainability (environmental, social, economic) in designing supply chain through OKRF and SCIS framework in the promotion of principles and practices for circular economy. Through a focused analysis of the semiconductor supply chain, it was found that these pandemic-induced disruptions, supply prioritization issues, and bullwhip effect created key vulnerabilities. I also looked at the specific challenges of low-volume high Mix (LVHM) manufacturing based on complexity and unpredictability in the customized production environment by pointing out how ADAPTIVE PLANNING, DIGITAL SOLUTIONS and SUPPLIER COLLABORATION help in managing the complexity and uncertainty in LVHM environments.

1.4 GAPS IDENTIFIED

Existing studies primarily focus on supply chain resilience, agility, and sustainability as discrete components, lacking a comprehensive framework that combines these features. While digital technologies like Artificial Intelligence, Blockchain and Internet of Things (IoT) have been identified as facilitators of supply chain efficiency, their role in real-time adaptation and predictive decision-making is largely unexplored. Moreover, research on semiconductor shortages is very limited, and existing articles only focus on reactive measures rather than predictive and preventive methodologies. Following the COVID-19 outbreak, interest in semiconductor shortages has surged, however, most of these studies fail to consider geopolitical and sustainability problems. The increasing issue of viability lacks industry-specific case studies within emerging economies. Most of the studies related to the VSC of semiconductor industries focus on existing economies like Taiwan, South Korea, China, etc. Additionally, for semiconductors, High-Mix Low Volume (HMLV) production strategies have been extensively scrutinized, and there exists a significant gap in literature for Low-Mix High Volume (LMHV) production strategies. Moreover, existing studies are mostly conceptualized and lack empirical evidence through industrial validation. Hence, this study examines the drivers of the viability of the semiconductor supply chains for LMHV production strategies, which fulfils the gap by considering factors such as resilience, adaptation, and risk reduction while using lessons from the COVID-19 semiconductor shortage to create a strategy framework for long-term and resilient supply chain management.

The limited knowledge base for VSC, if addressed, might offer valuable theoretical insights and practical recommendations. Analysing this can help overcome knowledge gaps and might clench the potential for improved policy-making and business actions.

1.5 OBJECTIVES OF THE PROJECT

The primary research objectives of this study are twofold:

- To identify and analyze key challenging factors in LMHV semiconductor supply chains using TISM to understand their interdependencies.
- To develop and implement strategic interventions to enhance resilience and adaptability in LMHV semiconductor supply chains.

These objectives are addressed by conducting a systematic literature review to extract and validate the most influential factors contributing to supply chain fragility and recovery in the semiconductor industry during and after COVID-19. Factors such as over-dependence on a few geographic regions, inadequate inventory buffers, lack of visibility in multi-tiered supply chains, delayed transportation, and raw material shortages will be analyzed through expert insights and structural modeling. By employing Total Interpretive Structural Modeling (TISM) or Interpretive Structural Modeling (ISM), the research will map out the hierarchical and causal relationships between these factors, helping decision-makers identify root causes and leverage points for intervention.

1.6 MOTIVATION

This contribution adds significantly to existing literature in several ways. First, it provides a semiconductor-specific application of structured modeling tools, which are more commonly used in general operations or logistics research. Second, it bridges the conceptual gap between the LMHV production strategy and risk management frameworks by presenting an integrated view of viability and resilience. Third, it aligns with ongoing policy shifts and industry trends that emphasize reshoring, regionalization, and greater supply chain transparency, offering strategic insights grounded in empirical data and structured modeling. The outcome will be a validated framework that can guide semiconductor manufacturers, policymakers, and supply chain managers in designing more robust LMHV production ecosystems that can withstand future global disruptions.

CHAPTER 2

METHODOLOGY AND EXPERIMENTAL WORK

2.1 Project Execution Stages

In this paper, we have opted for the Multi–Criteria Decision Making (MCDM) method. Within MCDM, several methods exist for the analysis of complex systems that typically involve multiple correlations between variables. ISM is one of the most prominent methods that offers a unique approach for constructing the conceptual hierarchy and investigating the dynamic relationships in complex problems. ISM focuses on the orderly connection between the various components of a system and interprets the relationships between the pieces, which depends on the opinions of a committee that assists in determining the correlation between them. Though ISM provides great flexibility for complex reasoning, its structural hierarchy is impacted by the standard ISM methodology's shortcomings, which include a failure to comprehend the relation between the parts. In such cases, Total Interpretive Structural Modelling (TISM), an extension of the traditional ISM method, effectively converts the inadequately defined and ill-reasoned models into clear and straightforward models, which the traditional ISM method may eradicate. One of TISM's primary improvements over the traditional ISM is that it establishes vital linkages between transitive relations and the development of the framework based on efficient connections found through the support of opinions from experts. TISM employs the Interpretive Matrix tool to capture the expert's casual reasoning and explains why the two things are interrelated. This study prefers TISM over other techniques like Decision-Making Trial and Evaluation Laboratory (DEMATEL), Weighted Product Model (WPM), and Analytic Hierarchy Process (AHP) because it explains the reasons behind each pairwise comparison, leading to a better grasp of the overall model. Since this study's broad application, a conceptual framework for the factors that contribute to viable and resilient supply chains was developed. The detailed methodology is mentioned in Fig. 2.1.

The section below explains the TISM methodology, which categorises factors. Further, the third section summarises the study's data collection method, which consists of a literature review and advice from the experts.

2.1.1 Total Interpretive Structural Modelling (TISM)

The process of the TISM approach used in this research has been described in eight successive phases that capture the approaches used to create the final overall interpretive structural model. It compares the drivers pairwise and identifies their relationships.

2.1.1.1 Stage 1. Determining and describing the factors

The first stage involves identifying and describing the factors with the help of a comprehensive literature review on viable and resilient supply chains, guided by an Expert Committee with personnel from industry and academia.

2.1.1.2. Stage 2. Defining Conceptual Relationships

The second stage entails creating contextual links between identified drivers to model their hierarchical levels. A paired contextual relationship is constructed between all factors to determine whichever is more prevailing, providing a total of $n \times (n-1)$ Relationships. For each paired relationship, the binary system questions (that is addressed using Yes/No) are asked about whether a driver (D_i) affects the driver (D_j), i.e., if D_1 impacts D_2, the contextual connection will be 'Y', otherwise, 'N'. When experts demonstrate the effect of a driver D_i on another driver D_j, they must present an explanation for why the relation is valid (if the answer is Yes/Y). This forms the interpretive knowledge set, which consists of rows reflecting. $n \times (n-1)$Pairwise connections and any supporting contextual relationships, if any.

2.1.1.3. Stage 3. Reachability Matrix and Transitivity Check

Based on the experts' opinions, the Initial Reachability Matrix (IRM) is prepared. Data from the interpretive knowledge base is represented as a binary. $n \times n$ Matrix, with the total number of driving factors. Pairwise enquiries provide 'Yes' or 'No' responses, which are then read as Yes = 1 and No = 0, i.e., if a driver D_i influences another driver D_j, the cell (D_i, D_j) is assigned a value of '1', otherwise, it is assigned '0', representing that the factor (D_i) doesn't affect the other factor (D_j). After the construction of the IRM, the Final Reachability Matrix (FRM) is prepared after carrying out a transitivity check. The Transitivity check is carried out to establish an indirect relationship between factor (D_i) and factor (D_j). According to the rule of transitivity, if driver (D_i) directly affects another driver (D_j), and driver (D_j) influences another driver (D_x), Driver D_i will likewise affect D_x. Similarly, if cell (i, j) is 0, then D_j may have a transitive connection with $D_{i,}$ which is known as an indirect link (denoted with 1 *). These links are further reviewed by experts to confirm that no insignificant transitive links exist in the FRM. This is done to provide a more consistent visualisation of the digraph. The Digraph should include the significant transitive and direct connection.

2.1.1.4. Stage 4. Defining the levels in the matrix

The fourth stage defines the levels in the matrix, also known as Level Partitioning. The Level Partitioning, like the ISM, describes the organisation of the items at each level. The constituents of reachability, antecedent, and intersection sets are grouped in a table; items at the top of the hierarchy don't have access to items below them. A top-level element's reachability and antecedent sets include the elements and any supporting elements, whereas its antecedent set just contains the element set. This procedure is repeated until all the levels are detected. These levels are used to create the Digraph and the final TISM Framework.

2.1.1.5. Stage 5. Developing the Digraph

In the fifth stage, level partitioning findings are used to graph the drivers in their respective levels using a Digraph. Higher-ranked drivers are organized at the peak, with lower-ranked drivers at the bottom. The drivers' hierarchy and connections help practitioners understand the impact of each driver on the resilience and viability of supply chains of semiconductors.

2.1.1.6. Stage 6. Interaction Matrix

The TISM is produced by integrating the digraph's connective information with the interaction matrix's interpretations. The nodes of the digraph are substituted with the interpretations from the interaction matrix. After translating the final digraph, a binary matrix representing transitive, direct, and significant links is created. An interpretative matrix is created to reflect the knowledge base specifically. Therefore, the resultant inter-relationships proposed in the TISM framework help in devising the strategies.

2.1.1.7. Stage 7. Designing the Total Interpretive Structural Model

In the seventh stage, the TISM model is developed utilising link interpretations obtained from the interaction matrix and digraph. The connections between the factors, as demonstrated using arrows, are replaced by the relationships between the drivers. The TISM's links express the rationale behind each pairwise relationship, making it easier to see the drivers.

2.2. Data Collection

The expert committee (EC) consist of 8 experts. The experts were selected from the Production and Operations domains. The detailed information on the experts consulted for this research, along with their experience, qualification and area of expertise, is illustrated in Table 1. A total of 10 drivers were selected based on the EC. These factors ensured the proper relevance and effectiveness within the research scope.

Table No. 2.1. Expert Committee Members

Sr. No.	Designation	Experience	Qualification	Expertise
1	Supply Chain Manager – Semiconductor Industry	12	Postgraduate	LMHV Manufacturing & Logistics
2	Procurement Head – Electronics Firm	14	Undergraduate	Global Sourcing & Vendor Management
3	Operations Manager – Chip Fabrication Plant	18	Postgraduate	Production and Capacity Planning
4	Risk Analyst – Semiconductor Sector	8	Postgraduate	Risk Mitigation & Disruption Analysis
5	Professor – Industrial Engineering	15	Doctorate	Supply Chain Resilience
6	Researcher – Sustainable Manufacturing	18	Doctorate	Viable Supply Chain & Circular Economy
7	IT Systems Head – Electronic Components Manufacturer	8	Undergraduate	Supply Chain Digitization
8	Supply Network Analyst – Global Tech Firm	7	Postgraduate	Forecasting & Network Optimization

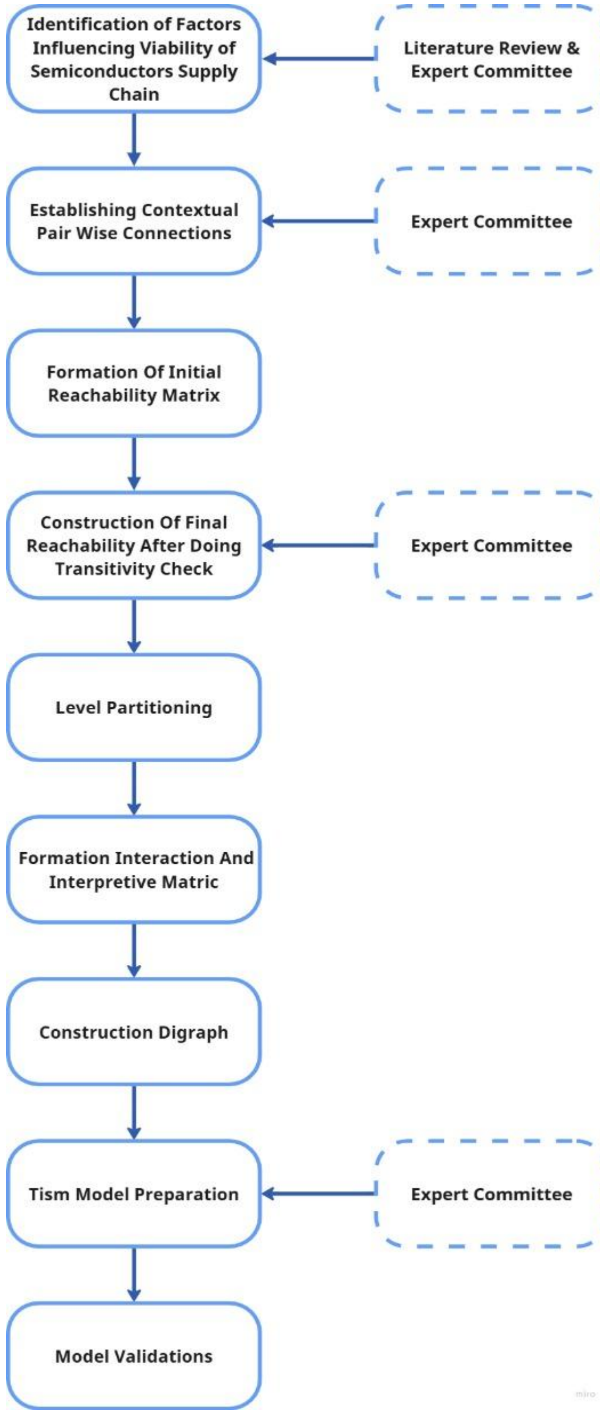

Fig. 2.1. Methodology flowchart

CHAPTER 3

RESULTS AND DISCUSSIONS

3.1. Results

According to the methodology described in the previous section, the factors affecting the viability of the semiconductor supply chains were identified, analysed and correlated through the TISM framework modelling. This section also reviews the SSC, which was selected as an example for this study, to demonstrate the application of a viable methodology.

3.1.1. Development of the framework

The first phase entailed identifying the factors that determine the viability of SSC. These factors were derived through a comprehensive literature review, industry reports and expert opinions from the EC. Finally, a total of 10 factors were identified.

Factors were selected, and their contextual relationships were constructed using the expert judgement of the EC. A total of 90 (10×9) paired-relationship questions were written and submitted to the EC to figure out the connection between any two factors, if any, and the justification behind it. The contextual links provided by the EC were used to create the interpretive knowledge set, which is also tabulated in Table 3.1.

Table No. 3.1. Identified drivers for viability of SSC.

Factor No.	Factors	Description	Citation
F1	Raw Material Supply Risks	Scarcity of key materials like gallium, silicon, and rare earth elements increases production costs and supply chain vulnerability.	Xiong, W., Wu, D. D., & Yeung, J. H. (2024). Semiconductor supply chain resilience and disruption: Insights, mitigation, and future directions. *International Journal of Production Research*, 1-24.
F2	Limited Strategic Partnerships and Alliances – data sharing risk	Forming strategic partnerships with suppliers, customers, and even competitors to share resources, knowledge, and capabilities, thereby strengthening the supply chain.	Varadarajan, R., Iacob Koch-Weser, C. R., Fitzgerald, J., Singh, J., Thornton, M., Casanova, R., & Isaacs, D. (2024). Emerging Resilience in the Semiconductor Supply Chain. *Boston Consulting*

			Group and Semiconductor Industry Association, 4.
F3	Talent Shortage and Workforce Constraints	A lack of skilled engineers and technicians in semiconductor manufacturing limits capacity expansion and technological advancement. Training and retaining highly skilled workers in semiconductor manufacturing is crucial to prevent talent shortages.	Rizi, A. D., Roy, A., Noor, R., Kang, H., Varshney, N., Jacob, K., ... & Asadizanjani, N. (2023). From talent shortage to workforce excellence in the CHIPS Act era: Harnessing industry 4.0 paradigms for a sustainable future in domestic chip production. *arXiv preprint arXiv:2308.00215*.
F4	Regulatory Compliance and Standards Adherence	Meeting global semiconductor manufacturing standards ensures seamless trade and prevents regulatory bottlenecks.	Lamsal, R. R., Devkota, A., & Bhusal, M. S. (2023). Navigating global challenges: the crucial role of semiconductors in advancing globalization. *Journal of The Institution of Engineers (India): Series B*, *104*(6), 1389-1399.
F5	Supply Chain Visibility and Traceability Gaps	Semiconductor supply chains are complex, spanning multiple countries and suppliers. Limited real-time data sharing and tracking mechanisms reduce transparency, leading to inefficiencies, counterfeit risks, and compliance challenges. Poor visibility also delays responses to disruptions, increasing operational risks. Implementing blockchain, AI-driven analytics, and digital supply chain platforms can improve tracking and resilience.	Ivanov, D. (2022). Viable supply chain model: integrating agility, resilience and sustainability perspectives—lessons from and thinking beyond the COVID-19 pandemic. *Annals of operations research*, *319*(1), 1411-1431.
F6	Capacity Constraints and Long Lead Times	Semiconductor fabs require high capital and time to scale, causing production bottlenecks. Lead times often exceed	Senoner, J., Netland, T., & Feuerriegel, S. (2022). Using explainable artificial intelligence to improve process quality: evidence from

		months, worsening supply shortages. Limited global capacity makes the industry vulnerable to demand fluctuations. Capacity diversification and regional expansion can help mitigate these risks.	semiconductor manufacturing. *Management Science*, *68*(8), 5704-5723.
F7	Supplier Concentration Risk	The semiconductor industry relies on a few key suppliers for critical materials and components, making it vulnerable to geopolitical tensions and disruptions. Over-reliance on specific regions increases supply chain fragility. Diversification, multi-sourcing, and regional partnerships can enhance resilience.	Thadani, A., & Allen, G. C. (2023). Mapping the Semiconductor Supply Chain. *Center for Strategic and International Studies, May, 11*.
F8	Logistics and Inventory Bottlenecks	Semiconductor supply chains face delays due to transportation disruptions, port congestion, and inefficient inventory management. Limited buffer stock and just-in-time (JIT) strategies amplify risks during crises. Digitization, predictive analytics, and regional warehousing improve logistics resilience.	Ivanov, D., Dolgui, A., & Sokolov, B. (2019). The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics. *International journal of production research*, *57*(3), 829-846.
F9	Geopolitical Instability	Trade tensions (e.g., U.S.-China conflicts) and export controls on critical semiconductor materials (e.g., rare earth metals) disrupt global supply chains and sourcing strategies.	Khan, S. M., Mann, A., & Peterson, D. (2021). The semiconductor supply chain: Assessing national competitiveness. *Center for Security and Emerging Technology*, *8*(8), 1-98.
F10	Interoperability Issues	Poor adoption of open data standards (e.g., OKRF,	Villar, A., Abowitz, S., Read, R., & Butler, J. (2024, March).

		SCIS) limits the ability to switch between suppliers and adjust production processes in real time.	Maximizing supply chain resilience: Viability of a distributed manufacturing network platform using the open knowledge resilience framework. In *Operations research forum* (Vol. 5, No. 2, p. 26). Cham: Springer International Publishing.

The knowledge base's binary representation led to the creation of the IRM, a 10 × 10 Matrix, refer to Table 3.2. The cells highlighted with '1' indicate a direct relationship between the contrasting factors; likewise, cells marked with '0' indicate no relationship between the factors. The matrix is also colour-coded for better understanding, i.e., the green cells indicate a direct relationship between the factors, whereas the yellow cells indicate the diagonal relationships. Based on this, the IRM is prepared, and the interpretation of the knowledge base is done.

Table No. 3.2. Initial Reachability Matrix

	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**
F1	1	0	0	0	0	0	0	0	0	0
F2	1	1	0	0	1	1	0	0	0	1
F3	0	0	1	0	1	0	0	0	0	0
F4	0	0	0	1	0	0	0	0	1	0
F5	1	0	0	0	1	1	1	0	0	0
F6	0	0	0	0	0	1	0	0	0	0
F7	1	1	0	0	1	0	1	0	0	0
F8	1	0	0	0	0	0	0	1	0	0
F9	1	0	0	1	0	1	0	0	1	0
F10	0	0	0	0	1	0	0	0	0	1

After forming the IRM, a transitivity check was done, which resulted in the FRM tabulated in Table 3.3. For example, if F_2 influences F_5, and similarly, if F_5 influences F_7, then there exists a transitive link between F_2 and F_7. All the blue cells indicate a transitive relationship between the factors. The knowledge base was updated based on the explanations provided by EC for the transitive linkages. In our case, all the transitive linkages are significantly important, as are all the fundamental logics between these factors.

Table No. 3.3. Final Reachability Matrix

	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**
F1	1	0	0	0	0	0	0	0	0	0
F2	1	1	0	0	1	1	1*	0	0	1
F3	1*	0	1	0	1	1*	1*	0	0	0
F4	1*	0	0	1	0	1*	0	0	1	0
F5	1	1*	0	0	1	1	1	0	0	0
F6	0	0	0	0	0	1	0	0	0	0
F7	1	1	0	0	1*	1*	1	0	0	1*
F8	1	0	0	0	0	0	0	1	0	0
F9	1	0	0	1	0	1	0	0	1	0
F10	1*	0	0	0	1	1*	1*	0	0	1

Based on the FRM, the next step of level partitioning was done on the FRM, these 10 factors were categorized into 4 levels as shown in Fig. 3.1.

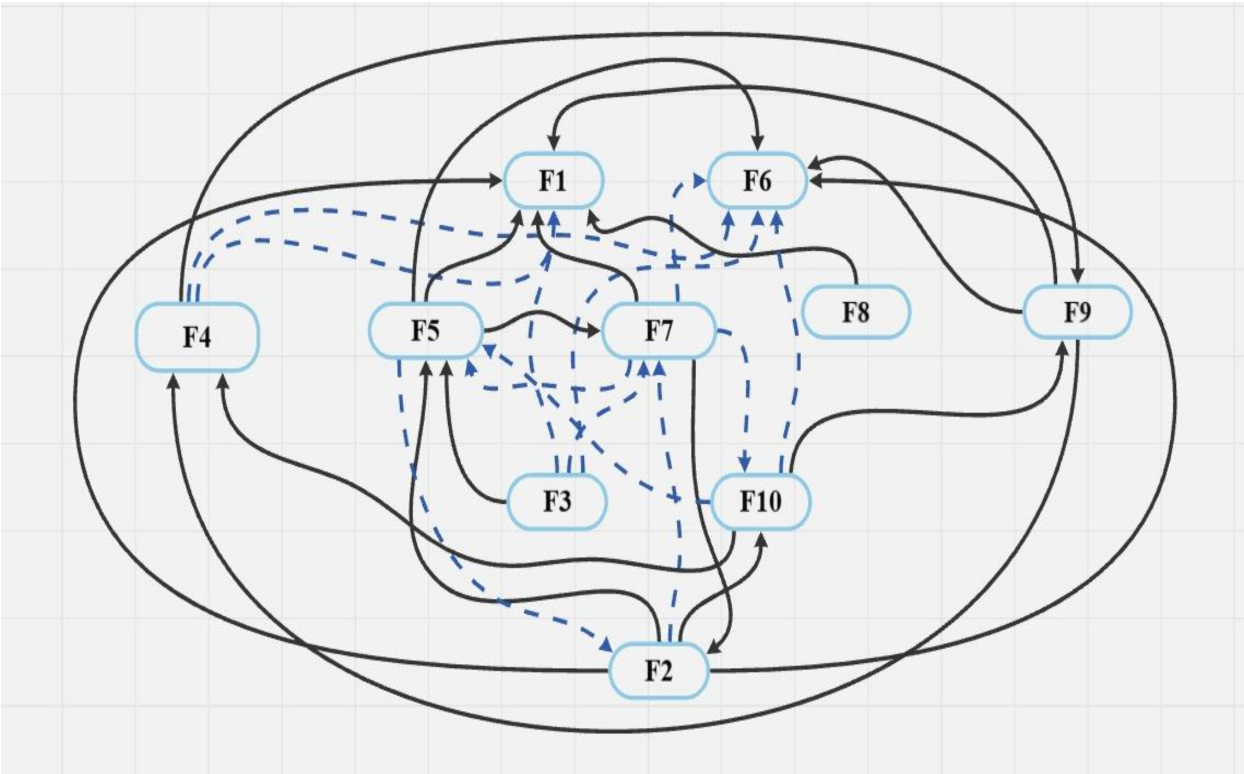

Fig. No. 3.1. Digraph of drivers for viability in SSC.

Level Partitioning can be described in 3 stages. The first stage consists of identifying the Reachability Set (R) and the Antecedent Set (A) for each factor. In the second stage, the Intersection set (I) was obtained through the equation. $I = A \cap R$ ………(eq.1)
The final stage consists of verifying whether the $I = R$. Based on this, the factor(s) were assigned the highest rank for each repetition, and subsequently, the factor(s) were excluded from the level partitioning, and this process was repeated to assign levels to all the factors.

As an example, the identification of the level for F1 is given below:

R = {1}

A = {1,2,3,4,5,7,8,9,10}

I = $A \cap R = \{1\}$

Therefore, R = I

For factor F_1, the equation $R = I$, is true; therefore, F_1 was assigned to Level 1. In the same manner, F_6 was also assigned to Level 1. Similarly, factors F_4, F_5, F_7, and F_9 were assigned to Level 2.

Factors F_3 and F_{10} were assigned to Level 3, followed by factor F_2, which was placed in the final level, namely, Level 4.

According to the FRM, the digraph was constructed to understand the link between the factors in Fig. 3.2. Based on the level partitioning step, Level 1 factors, F_1 and F6, are placed at the top-most level, and the Level 4 factor, F_2, is located at the bottom-most level. Significant transitive linkages are demonstrated by dashed arrows, whereas the direct linkages are represented by continuous arrows. Since the TSIM model follows a bottom-up approach, two pair-wise relationships, namely, F_5-F_2 and F_7-F_2, were removed from further analysis as their contribution is not meaningful for our model.

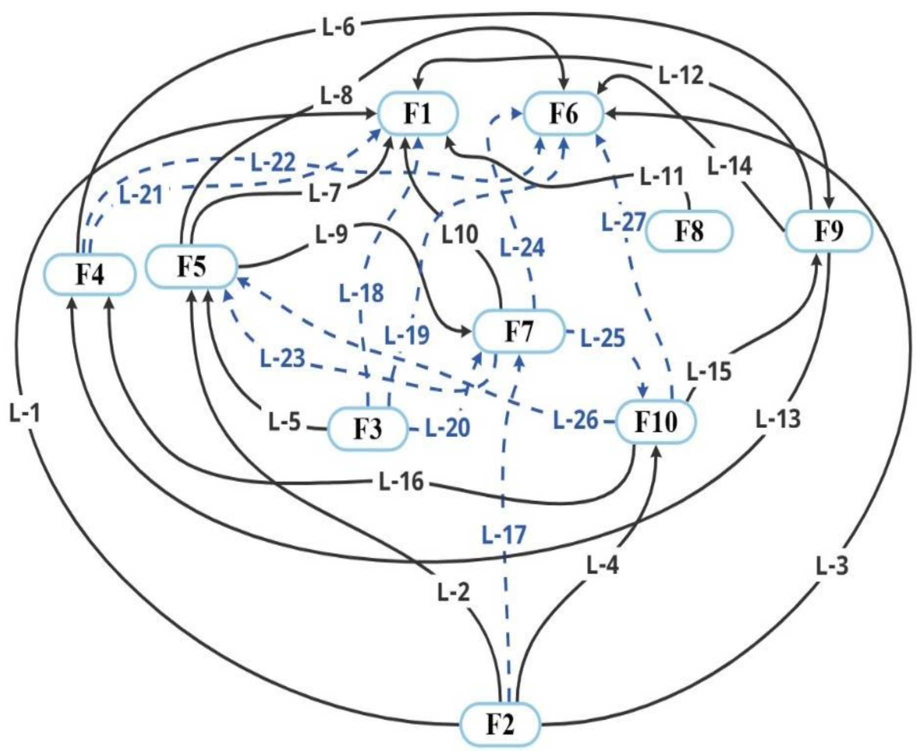

Fig. No. 3.2. Total Interpretive Structural Model of drivers for viability of SSC.

The TISM model was constructed based on the pair-wise relationships. After plotting the digraph, all the link interpretations were done. The arrows in the digraph symbolize the contextual relationship between the factors. A total of 27 links, including 10 transitive links, were identified and plotted accordingly.

The proposed model was then assessed by the expert committee. This strategy gathered feedback from more domain experts and strengthened the model's validity. The results are shown in Table 3.4. Based on the expert committee evaluation, all the links were accepted except one transitive link, L20. L20 represents the effect of the factor Talent Shortage and Workforce Constraints (F_3) on Supplier Concentration Risk (F_7), which, according to the EC, is futile as its average score is less than 3. Except for link L20, all the links are considered effective and have an average score greater than 3. Hence, a total of 26 links triumphed as relevant linkages. The validated model was plotted again without the link L20 (refer Fig. 3.3).

Table No. 3.4. Interpretation statements and their validation.

Link no.	Factors	Explanation	Expert Responses								Avg. expert score	Accept/ reject
			E1	E2	E3	E4	E5	E6	E7	E8		
L1	F2 → F1	Limited partnerships reduce access to diversified suppliers, increasing raw material supply risks.	5	5	4	3	3	5	5	4	4.25	Accept
L2	F2 → F5	Weak partnerships hinder data sharing, creating visibility gaps in the supply chain.	4	3	5	3	3	3	4	4	3.625	Accept
L3	F2 → F6	Poor collaboration limits capacity optimization, worsening long lead times.	4	5	4	4	3	4	3	3	3.75	Accept
L4	F2 → F10	Misaligned partnerships lead to interoperability issues across systems.	4	3	4	4	5	3	4	5	4	Accept
L5	F3 → F5	Talent shortages limit the ability to implement visibility-enhancing technologies like IoT or blockchain.	5	4	4	5	3	4	5	3	4.125	Accept
L6	F4 → F9	Regulatory compliance gaps create geopolitical tensions by conflicting with international standards.	5	4	4	4	4	4	3	5	4.125	Accept
L7	F5 → F1	Visibility gaps prevent proactive identification of raw material shortages.	4	4	3	5	4	3	3	3	3.625	Accept
L8	F5 → F6	Poor visibility reduces demand forecasting accuracy, worsening capacity constraints.	4	4	3	4	3	4	3	5	3.75	Accept

L9	F5 → F7	Lack of traceability increases reliance on concentrated suppliers.	5	5	5	3	5	5	3	3	4.25	Accept
L10	F7 → F1	Supplier concentration raises risks of raw material shortages during disruptions.	5	4	5	3	5	5	3	5	4.375	Accept
L11	F8 → F1	Logistics bottlenecks delay raw material deliveries, increasing supply risks.	3	3	3	3	4	3	4	4	3.375	Accept
L12	F9 → F1	Geopolitical instability disrupts trade routes, impacting raw material availability.	4	4	3	5	5	3	5	5	4.25	Accept
L13	F9 → F4	Geopolitical tensions create conflicting regulatory requirements across regions.	4	5	5	3	5	5	4	4	4.375	Accept
L14	F9 → F6	Political instability disrupts manufacturing hubs, worsening capacity constraints.	4	4	3	5	5	3	4	3	3.875	Accept
L15	F10 → F9	Interoperability issues hinder cross-border collaboration, amplifying geopolitical risks.	4	3	3	5	4	3	3	3	3.5	Accept
L16	F10 → F4	Misaligned systems complicate compliance with global regulatory standards.	3	4	3	5	3	4	3	3	3.5	Accept
L17	F2 → F7	Limited partnerships reduce collaboration opportunities, increasing reliance on concentrated suppliers.	5	4	3	5	3	4	3	4	3.875	Accept
L18	F3 → F1	Talent shortages hinder procurement planning/sourcing strategies, causing raw material delays.	4	5	3	5	3	5	5	5	4.375	Accept
L19	F3 → F6	Workforce constraints slow production efficiency, worsening capacity bottlenecks.	5	4	3	4	3	5	5	5	4.25	Accept
L20	F3 → F7	Lack of skilled staff limits supplier diversification efforts, raising concentration risks.	2	3	3	2	3	2	2	2	2.375	Reject
L21	F4 → F1	Regulatory delays/complexities restrict access to compliant raw material sources.	3	4	3	5	3	3	3	3	3.375	Accept
L22	F4 → F6	Compliance audits slow production processes, extending lead times.	3	5	5	5	4	5	3	3	4.125	Accept

L23	F7 → F5	Supplier concentration reduces incentive to track sub-tier suppliers, creating visibility gaps.	3	4	5	5	5	5	5	3	4.375	Accept
L24	F7 → F6	Overreliance on few suppliers limits flexibility to address production capacity shortages.	5	4	5	5	3	4	3	3	4	Accept
L25	F7 → F10	Concentrated suppliers resist adopting standardized systems, causing interoperability conflicts.	4	3	4	3	4	4	4	3	3.625	Accept
L26	F10 → F5	Incompatible systems between stakeholders prevent seamless data sharing for traceability.	3	4	3	4	3	4	5	4	3.75	Accept
L27	F10 → F6	Interoperability gaps disrupt real-time production planning, worsening capacity utilization	4	5	5	3	4	3	4	3	3.875	Accept

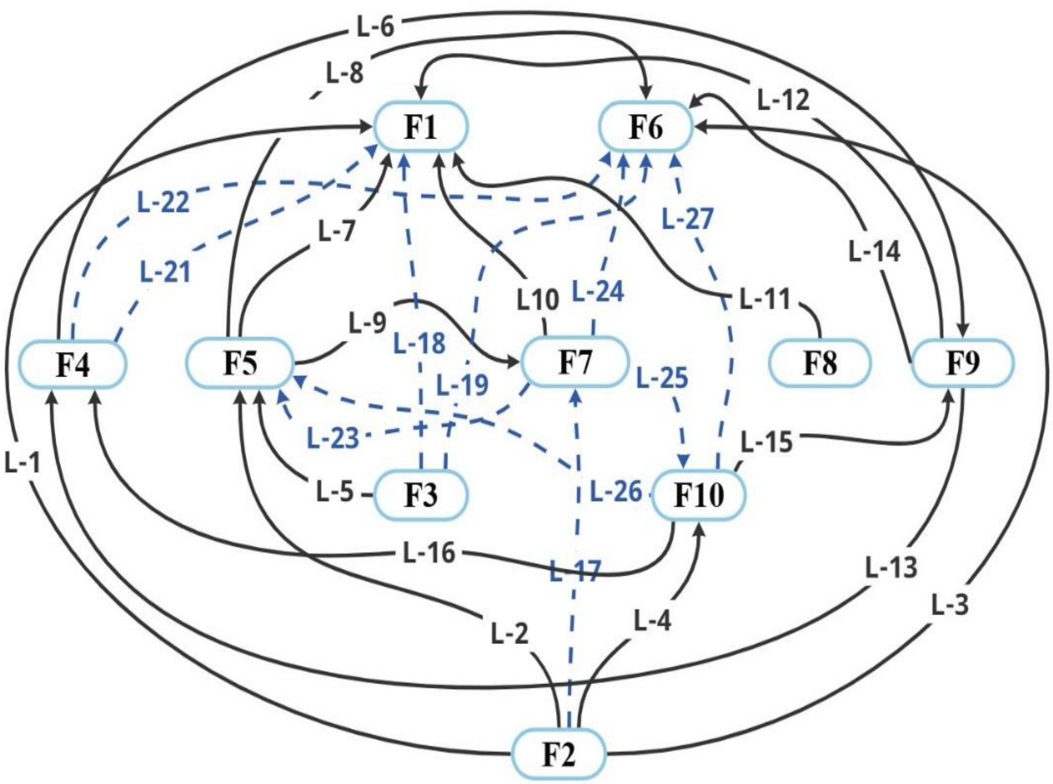

Fig. No. 3.3. Validated Total Interpretive Structural Model.

3.2. Discussion

The study identified 10 factors that affect the viability of a functional semiconductor supply chain. The parameters were analysed following the advice of academic institutions and industry experts.

The level partitioning created a digraph containing four levels, with the top level indicating the most dependant components and the bottom level reflecting the major driving factor in the collection. The TISM model presents a hierarchical structure of investigated drivers of the viability of an SSC.

3.2.1 Findings

According to TISM, the factor Raw Material Supply Risk (F_1) and Capacity Constraints and Long Lead Times (F_6) are at level 1. Since Semiconductor manufacturers rely highly on raw materials, the concerns associated with raw material supply were evident during the COVID-19 pandemic. Every sector, including electronics and automobiles, was hit. Because of the global lockdown during the pandemic, the raw material supply was severely disrupted, resulting in shortages, delays, and price increases across a variety of businesses. Similarly, because of pandemic procedures, industries had to reduce labour interaction, resulting in reduced production rates and longer lead times due to raw material supply delays. Due to these conditions, every company faced operational inefficiencies and reduced responsiveness. According to Ramani et al. (2022), systemic interruptions in raw material supply cause cascading failures, especially in the automobile sectors. Business capacities along with limitations produce complex issues that cause both manufacturing postponements and cost objectives and market competitiveness deterioration. Adequate mitigation measures are essential because organizations that lack them will suffer from long-term disruption and reduced revenue streams.

At Level 2, factors that are more supply chain risk-focused occupied this level. These include factors like Regulatory Compliance and Standards Adherence (F_4), Supply Chain Visibility and Traceability Gaps (F_5), Supplier concentration risk (F_7), Logistics and Inventory Bottlenecks (F_8), and Geopolitical Instability (F_9). The stability of supply chains depends heavily on regulatory compliance because noncompliance results in financial consequences, reputation damage and operational disruptions. Echoing its position at Level 2 demonstrates that supply chain resilience is affected by this factor, yet it does not serve as the fundamental cause of other identified risks. The inability to track supply chain activity greatly affects operation management, especially when tracking raw materials alongside finished products in specific industries. Supply chain visibility and traceability drive operational effectiveness by providing real-time monitoring combined with clear visibility regarding shipments so that system interruptions reduce and foster business stability and adaptability to universal uncertainties (Razak, Hendry, & Stevenson, 2023). Operating with a few suppliers creates supplier concentration risk because any form of supply disruption brings widespread effects to the entire supply chain. Business operations become less flexible and resilient when organizations heavily depend on a few suppliers because of an overreliance on a limited number of entities. Such reliance creates delays, cost, and manufacturing inefficiencies. To secure supply chain stability, companies need to expand their supplier networks and create alternate plans.

Using level partitioning, Talent Shortage and Workforce Constraints (F_3) and Interoperability Issues (F_{10}) are at level 3 of the hierarchy and can be categorized as linkage factors. They suggest that the system has a strong driving power and a high internal dependency. These are essential connections of numerous supply chain risks, with fluctuations in intensity for any of these factors having a significant impact on other risks and being impacted by them. Lack of talent may cause supply chain operations to fail by restricting available skilled workers, delaying output, and making adaptability to new technologies more difficult, exacerbating all other operational inefficiencies. Hurdles created by interoperability concerns in general include hurdles to smooth integration across multiple platforms, limitations on information transmission and cooperation, and automated processing. Also, according to Chein, Kuo, and Lin (2024), semiconductor manufacturing examines pricing, demand planning, capacity portfolio, cost management, etc., in an improved sustainable supply chain resilience with advanced analytics. Firms can thereby at least better allocate resources, reduce risks, and enhance operational efficiency if they integrate real-time data and predictive modelling.

The last level consists of Limited Strategic Partnerships and Alliances (F_2). It can also be classified as the strongest driver since it has the highest driving power and the weakest dependence power, according to the TSIM model constructed. Because of the bottom-up approach, a direct link between F_7-F_2 and a transitive link between F_5-F_2 was removed from consideration. Even after that, it was observed that F_2 influenced factors F_1, F_5, F_6, and F_{10} directly, and an indirect relation exists with F_7. Weak supplier networks are created because a lack of strong partnerships leaves supplier networks lacking back-up sources of supply of raw materials and makes suppliers weak in bargaining power. It also exacerbates capacity constraints and long lead times, and companies also struggle to secure reliable production capacity without collaborative agreements. On top of that, fragmented communications cause visibility and traceability gaps to widen as standardized data-sharing mechanisms are not in place. As companies rely on few suppliers, supplier concentration risk grows, and the companies become vulnerable to disruptions. To mitigate such risks, exploration of different economies and suppliers should be explored. Thus, according to Ishak, Shaharudin, Salim, Zainoddin, and Deng (2023), mitigating such risks can make the SSC more responsive and resilient.

Through the bottom-up approach, we have Limited Strategic Partnerships and Alliance (F_2) in the lowest level (Level 4). To mitigate this issue, strategies like collaborative partnerships with essential suppliers and OEMs using Joint Business Plan (JBP), using of cloud-based platforms for real-time data sharing, and develop explicit data governance policies to promote trust and maintain privacy.

Similarly, in Level 3, factors like Talent Shortages and Workforce Constraints (F_3) and Interoperability Issues (F_{10}) can be mitigated. For factor F_3, regular upskilling and training programs for technological advancements like digital SCM and automation, flexible work environments, and collaborative plans between industry and academia can foster talent retention and new talent attraction. For factor F_{10}, collaborate with industry consortiums (such as SEMI and IPC) to coordinate technical standards, using standardized systems with open-source APIs and protocols and integrating cloud-based SCM platforms.

Level 2 consists of factors like Regulatory Compliance and Standards Adherence (F_4), Supply Chain Visibility and Traceability Gaps (F_5), Supplier Concentration Risk (F_7), Logistics and Inventory Bottlenecks (F_8), and Geopolitical Instability (F_9). Risks related to factor F_4 can be resolved by setting automated compliance management tools like SAP, GRC, etc., maintaining proper Standard Operating Procedures (SOPs), and regular auditing of suppliers to maintain industry-specific standards. Factors like F_5, F_7, and F_8 are critical risks related to operational efficiency; such issues can be reduced by opting strategies like, multiple suppliers or multi-sourcing strategies, investing in the development of local suppliers, using digital technologies like RFIDs, IoT, etc., to make real-time monitoring and benchmarking possible, collaboration with 3PL/4PL for managing supply chain logistics, and using near-shoring and distributed warehousing strategies. Subsequently, to mitigate geopolitical risks, strategies like diverse supplier pools and establishment of local manufacturing and regional hubs to reduce cross-boundary dependency.

Factors like Raw Material Supply Risk (F_1) and Capacity Constraints and Long Lead Times (F_6) are located at the uppermost level, i.e., Level 1. Strategies to solve Raw Material Supply Risks are maintaining inventory buffers for high-risk materials, i.e., Silicon, Germanium, Copper, Gold, etc. Mitigating Capacity Constraints and Long Lead Times can be done by implementing Flexible

Manufacturing Systems (FMS) and Modular Production Lines, using better forecasting methods to optimize capacity, and maintaining buffer stocks to manage production issues during conditions like the COVID-19 pandemic.

3.2.2. Limitations

This research focuses on the viability of the semiconductor supply chain but contains certain limitations. Since the research depends on existing literature along with professional expertise, this method introduces personal opinions and bias, which can potentially reduce the universal applicability of the detected patterns. Also, this study doesn't focus on any digital technologies that affect the SSC. Geo-political factors, together with policy changes that affect supply chain dynamics, receive limited modelling in this analysis. Modern supply chains miss out on important opportunities because this project fails to incorporate advanced digitization and AI technology despite their growing impact with real-time data processing, predictive analysis, and machine automation. Although the study addresses vital challenges, it omits specific investigations of regional differences and organizational capabilities affecting supply chain resilience at different levels and across regions.

CHAPTER 4

CONCLUSION

The present study sets forth a strategically grounded framework to enhance the **resilience and viability of semiconductor supply chains** operating under the **Low Mix High Volume (LMHV)** production model. With semiconductors being one of the most critically affected sectors during the COVID-19 pandemic, this research addresses a pressing need to develop context-specific interventions that go beyond general supply chain frameworks. The pandemic exposed a harsh truth: despite being highly optimized for efficiency, semiconductor supply chains lacked the structural resilience needed to withstand sudden global shocks. Existing literature revealed several gaps—most notably, a lack of empirical validation and sector-specific strategies tailored to LMHV characteristics. In response to this, our study offers a unique and novel contribution by applying the **Total Interpretive Structural Modelling (TISM)** approach, which is both interpretive and structured, allowing us to identify, categorize, and interlink the key factors that drive or hinder resilience in such systems.

What distinguishes this approach from traditional modelling techniques is its ability to integrate **expert insights** directly into the hierarchical mapping of interdependent drivers. While earlier studies often relied on isolated variables or theoretical simulations, our framework uses **real-time industry knowledge** to bring out the nuanced dependencies that exist within semiconductor networks—such as supplier concentration risk, limited sourcing flexibility, inadequate forecasting mechanisms, and overdependence on singular production geographies. Through the **TISM method**, we successfully fulfilled our primary objectives: (1) to identify and analyze key challenging factors in LMHV semiconductor supply chains and (2) to develop and implement strategic interventions to enhance resilience and adaptability. The structured hierarchy derived from TISM made it possible to distinguish between the foundational and consequential factors, enabling us to propose **targeted, impactful interventions** rather than generic.

Beyond merely responding to the aftermath of COVID-19, this research looks forward—recognizing that **resilience and viability are not static end goals** but continuous, dynamic processes that must evolve with the industry. The semiconductor sector, by its very nature, is fast-paced, capital-intensive, and globally integrated. This makes it uniquely vulnerable to disruptions, whether due to geopolitical instability, technological transitions, or demand surges. Our findings advocate for regular re-evaluation of the identified critical factors and their interconnections, as shifts in market dynamics, production technologies, and global trade regulations can quickly render even the most well-established models obsolete. By incorporating industry expertise and contextual intelligence, this research doesn't just create a model—it offers a **living strategic tool** for future planning, scenario testing, and proactive decision-making.

In essence, this project act as bridge between academic research and industrial application. It invites supply chain managers, policymakers, and strategic planners to rethink their approach to LMHV production—not simply as an efficiency-driven model but as one that must be safeguarded with layered resilience. The strength of this research lies not just in the modeling technique, but in its **sector-specific relevance, empirical grounding, and operational applicability**. By adopting the proposed interventions, companies in the semiconductor space can better position themselves to face future disruptions—not reactively, but strategically and preemptively. While this study offers a solid foundation, future research can build on it by incorporating real-world case studies, extending the approach to other high-stakes manufacturing sectors, and evaluating the long-term sustainability of the suggested interventions. Nevertheless, the framework developed here presents a **significant leap** toward developing a resilient and viable semiconductor supply chain model tailored for the LMHV paradigm, with insights that remain relevant well beyond the COVID-19 context.

Author Contributions

This research project was a result of collaborative and complementary efforts by both authors:

- Prabhat Dutta (21BME0154) took the lead in fulfilling: to identify and analyze key challenging factors in LMHV semiconductor supply chains using TISM to understand their interdependencies. He analyzed the TISM outputs to design relevant interventions, engaged with industry experts to validate the critical factors, and led the application of the TISM methodology to develop the hierarchical structure of influencing elements.
- Davargha Chakravorty (21BME0215) was primarily responsible for fulfilling: to develop and implement strategic interventions to enhance resilience and adaptability in LMHV semiconductor supply chains. He carried out an in-depth literature review, explored practical applications of the proposed framework in the post-COVID context, and translated the findings into actionable insights for industry stakeholders.

4.1 Limitations

This research focuses on the viability of the semiconductor supply chain but contains certain limitations. Since the research depends on existing literature along with professional expertise, this method introduces personal opinions and bias, which can potentially reduce the universal applicability of the detected patterns. Also, this study doesn't focus on any digital technologies that affect the SSC. Geo-political factors, together with policy changes that affect supply chain dynamics, receive limited modelling in this analysis. Modern supply chains miss out on important opportunities because this project fails to incorporate advanced digitization and AI technology despite their growing impact with real-time data processing, predictive analysis, and machine automation. Although the study addresses vital challenges, it omits specific investigations of regional differences and organizational capabilities affecting supply chain resilience at different levels and across regions.

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