Supply chain transparency for sustainability – An intervention-based research approach

Purpose: The COVID-19 pandemic has impacted all manufacturing sectors from basic products to luxury goods including the automobile industry. This has necessitated a new line of research on competency building, transparency, and sustainability in automotive supply chains. In this study we examine the competencies required to improve the automotive supply chain routine operations to address the parts supply crisis from multitier suppliers in the post-COVID-19 environment. We also propose a list of competencies required in the automotive supply chains to deploy the Transparency for Sustainability (TfS) framework on a long-term basis.

Design/methodology/approach: We have adapted a cross-case study process using intervention-based research (IBR) and a design science approach for use in this study and used multiple sources for data collection such as published literature, operational experience, and critical opinions of Original Equipment Manufacturer (OEM) representatives. The research design includes interviews with global OEMs practitioners as one of the relevant sources of information.

Findings: The impact of the COVID-19 pandemic outbreak on automotive manufacturing operations and global supply chains is unprecedented. The Transparency for Sustainability (TfS) framework cycle has been validated using the real-world semiconductor supply crisis which deals with multitier sustainable supply chain management (MTSSCM) and we found that there are competency gaps when compared with existing literature. The list of key competencies identified along with the formulation of design propositions to facilitate both the supply crisis and collaboration among automotive firms to enhance their business performance were also presented.

Research limitations/implications: The COVID-19 pandemic is impacting the automobile sector significantly. This situation has created many opportunities and obstacles, but this paper only considers the automotive semi-conductor shortage situation, which may be resolved in the near future when there are more installed capacities. Therefore, it is unclear whether the proposed responses will result in long-term solutions. Further adjustments may be needed to revisit the TfS framework. Our research paper only addresses the automotive side of the current supply crisis, but more sustainability issues may arise in the future, which need to be dealt with separately.

Practical implications: Research findings may prove particularly interesting to global automotive vehicle manufacturers, suppliers and policy makers who are seeking to understand multitier supply networks to resolve the current challenges associated with the post-COVID-19 pandemic situation.

Originality/value: In addition to contributing to developing competency requirements, this study enhances the evolving research stream of MTSSCM by linking it to wider research applications of intervention-based research coupled with design science.

Keywords: Multitier supply chains, Sustainability, Automotive, Intervention-based research, Design science, Covid-19.

Paper type: Research paper

1. Introduction

In recent years, automotive supply chains (SCs) have come under increasing pressure to change to green operations. As a result, SC ecosystems require new approaches to address a) the sustainable production of products to meet societal and political demands and b) adoption of electric vehicles (EVs) in a broader scale towards sustainability (Casper and Sundin, 2020). Lean techniques such as life cycle assessments and value-stream mapping have primarily been used to assess the performance of original equipment manufacturers (OEMs) and tier-1 suppliers in the past (Sobral et al., 2013; Zhu et al., 2013). However, due to the recent global supply chain vulnerability caused by COVID-19 and other supply chain disruption events, risk management must be approached in a new way (Wang-Mlynek and Foerstl, 2020).

The manufacturing capacities at the supplier end were often diminished in the COVID-19 situation because government-led lockdowns and border regulations impacted transportation of goods (Chowdhury et al., 2021). Also, Ivanov and Dolgui (2020) highlight the bullwhip effect caused by the swift increase in demand, as well as the reduction in installed production capacity during the pandemic. Bullwhip effects can increase inventory costs, transportation costs, and hiring and firing of the workforce (Wang and Disney, 2016). Furthermore, Steers (2021) notes that the blockage of the Suez Canal by the Evergrande container ship in 2021 delayed over 300 container ships, causing supply chain disruptions in the automotive industry and elsewhere. Dou et al. (2018) mention that the growing pressure from stakeholders requires organizations to go beyond existing organizational boundaries into multitier sustainable supply chain management (MTSSCM) to improve decision making. Accordingly, many researchers and practitioners have been working within their specific competencies to tackle the supply chain crisis from different perspectives. Design science, an outcome-based research methodology, aims to bridge the gap between practice and academia through empirical evaluation of how designs work in the field with the help of domain knowledge (Holloway et al., 2016).

Due to a global chip shortage, the automotive industry has been unable to meet the growing demand, and offers limited transparency and visibility (Hawkins, 2021). A critical aspect of this research is to determine how the current multitier sustainable supply chain associated with

electronics, control, and infotainment modules procurement which involve semiconductors is dealt with by global automotive OEMs to develop the right competencies to reduce or eliminate the impact of chip shortages.

The research purpose is addressed based on a combination of a *case study* approach and a *design science* approach (Holmstrom et al., 2009). To address the research problem, this study employs the transparency for sustainability (TfS) framework (Fraser et al., 2020). By assessing the TfS framework implementation for supply chain risk situations and improving transparency, this study reveals additional competency requirements that are needed to handle MTSSCM in the automotive industry (Fraser et al., 2020; Garcia-Torres et al., 2019). To achieve our objective, we use multitier sustainable supply chain management (MTSSCM) to overcome the lack of transparency across the supply chain network and to ensure that sustainability measures are implemented, adopted, and further enhanced. This study also focuses on driving sustainability in the multitier supply chain by improving the visibility or transparency using digital transformation and collaboration through building relationships across the buyer and the seller. Furthermore, in a constrained demand-supply environment due to COVID-19, this study's findings complement practitioners' knowledge on how transparency- and traceability-associated competencies bring improvements across multitier suppliers that can generate added-value for business which also acted as a research motivation. We address the following research questions.

RQ1. When compared to real-world multitier sustainable SC challenges in automotive OEMs, what competencies are required to deploy the TfS framework?

RQ2. In the context of a disruptive situation, what competencies are required across the areas of MTSSCM to deal with the supply crisis?

Our study contributes to the growing literature on multitier supply networks by empirically investigating organizations' competencies to address the supply crisis caused due to COVID-19 pandemic situation. We also provide the maturity levels of these competencies in MTSSCM including analytical and data management skills managed by the focus automotive firms identified to deploy the TfS framework. The rest of this article is organized as follows: Section 2 presents a brief literature review focused on the concepts of multitier supply chain transparency, sustainability, and motivation. Section 3 presents the research methodology which involves using a cross-case study approach using cross-case study design with the use of the context-intervention-mechanism-outcome (CIMO) method, case selection, and data collection and analysis. Section 4

describes the case study and analyzes it in terms of competencies needed for dealing with MTSSCM in the real world, compared to the TfS framework, while section 5 discusses the results, identifying the mechanisms and actionable design propositions for enhancing competencies across supply chain areas based on three automotive firms, and comparing them to the literature. Section 6 reports the research conclusions and comparative competencies among the focus firms.

2. Theoretical background and motivation

Our research study is motivated through practical complications experienced by leading car manufacturing companies, due to shortage on supply of semiconductors during pandemic outbreak. In this line, we draw viewpoints from the existing literature of multitier supply chains and their transparency in sustainability approaches.

2.1. Multitier supply chain - Semiconductor demand and supply flow

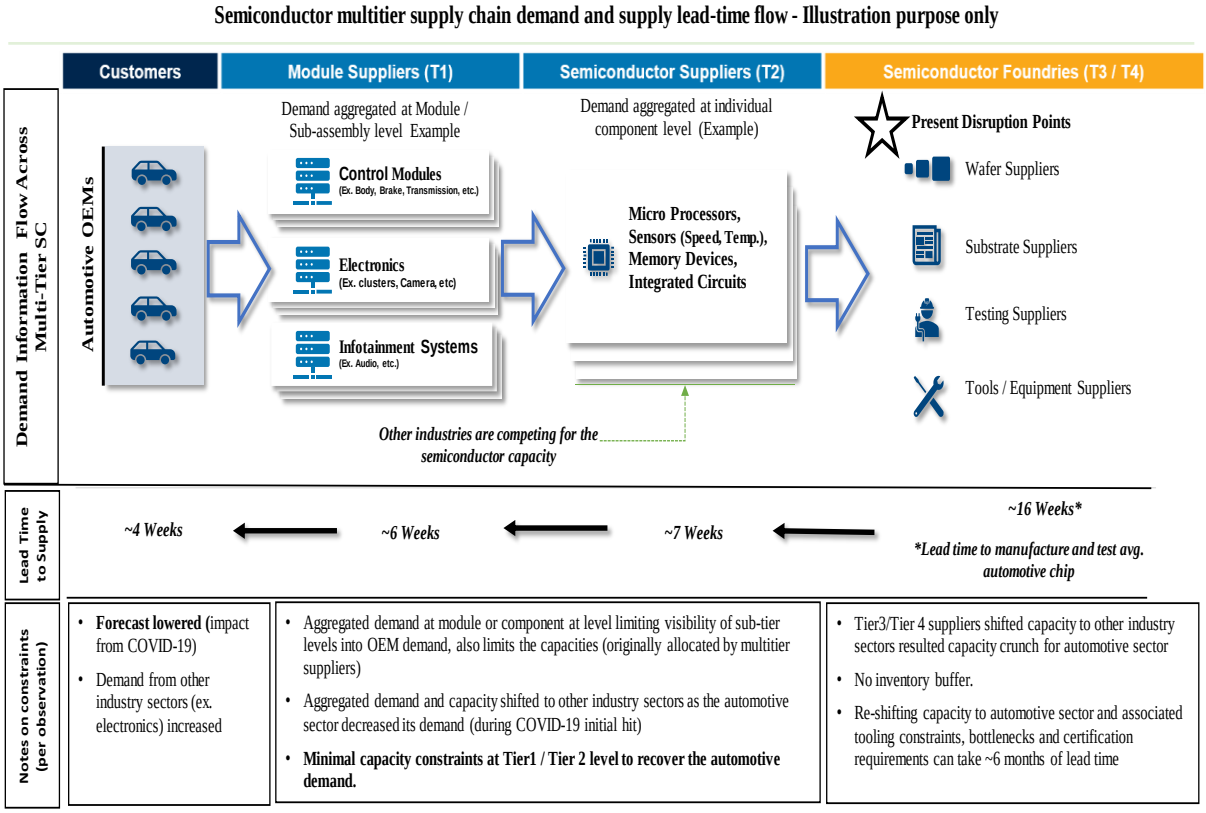


Figure 1: Multitier semiconductor supply chain demand and supply lead-time flow

Figure 1 describes a multitier supply chain with lead-times to supply at each stage of the chain. 1. Multitier supply chain stages are OEMs, module suppliers (tier 1), semiconductor suppliers (tier

2), and semiconductor foundries (tier 3 and tier 4) to describe how information flow and physical parts flow are affected at each stage, including the associated constraints. The bottom section of the figure depicts the constraints based on observations at each stage (e.g., material forecast reduction impacts from OEMs under COVID-19 scenarios acted as a constraint for calculating aggregate demand for module suppliers (tier 1)).

2.2 Transparency for sustainability in supply chain management

The Toyota approach is based on transparency, which serves as a shared process knowledge within the supply chain. According to Covey (2006), Toyota develops long-term relationships with their suppliers through their transparency behavior, thus enabling SC collaboration through long-term relationships. Trienekens et al. (2012) define Transparency in SC as the degree to which all stakeholders within the SC have access to and a common understanding of product-related information. Egels-Zanden and Hansson (2016) report that transparency expectations for firms have extended to SCs, which have led to an SC transparency concept. This in turn discloses information such as supplier names and sustainability conditions related to purchasing and preparation of products. Gardner et al. (2019) propose a framework for SC transparency that includes six types of information – effectiveness, impact, policy and commitment, activity, transaction, and traceability. This implies that traceability is seen as an important tool in achieving transparency in the SC (Fraser et al., 2020). By increasing SC efficiency, supply chain visibility can improve internal stakeholders' performance in terms of operational, social, and environmental metrics (Dubey et al., 2020; Tang and Sodhi, 2019). The visibility of the SC benefits external stakeholders, as it helps to build trust and compliance with regulations by disclosing the SC information publicly (Biktimirov and Afego, 2021; Smit et al., 2020). Transparent and sustainable SCs enable the fitness of embracing the resource-based view (RBV) of a firm. The SC evolves based on the resources and competencies that the firm holds to create business value (Barney, 1991). To achieve the optimal resources in sustainability, Sarkis (2021) informs organizations on how to deal with the SC dimensions such as environmental, social, and economic sustainability with the help of Industry 4.0 enabled-technologies, automation, and data exchange systems. Similarly, Sajjad (2021) discusses the global supply chain sustainability challenges and provides a pathway for organizations to develop resilience in a post-COVID environment. Fan et al. (2020) explain the importance of interpersonal relationships in dealing with supply-side resilience and risk management behaviors.

Some other researchers describe sustainability in SCs in relation to material flow and the nature of businesses. For example, Garcia-Torres et al. (2019) describe sustainability as the firm's management of the resource flows (information, material, and financial) of the system to ensure its economic viability, with limited or no harm to its natural and social surroundings. Considering the interconnected and dynamic nature of modern business, it is essential to periodically review the firm's external and internal competencies to maintain competitive advantage and adapt to rapid changes in the business environment (Eisenhardt and Martin, 2000; Teece et al., 1997). Multitier sustainable SCM (MTSSCM) frameworks infer from firms' knowledge about supply chain tier-structures (Tachizawa and Wong, 2014; Wilhelm et al., 2016) or they are generated using supply chain mapping to learn sustainability (Fraser et al., 2020). Garcia-Torres et al. (2019) focus on traceability for sustainability during disruptive times and provide a new approach for its application to complex SCs. Furthermore, the have developed a traceability framework for sustainability based on sustainability and multitier supply chain management for the apparel industry. They argue that visibility and transparency are necessary for the MTSSCM to be effective. Integration of visibility, traceability, and associated SC innovation actors must be considered.

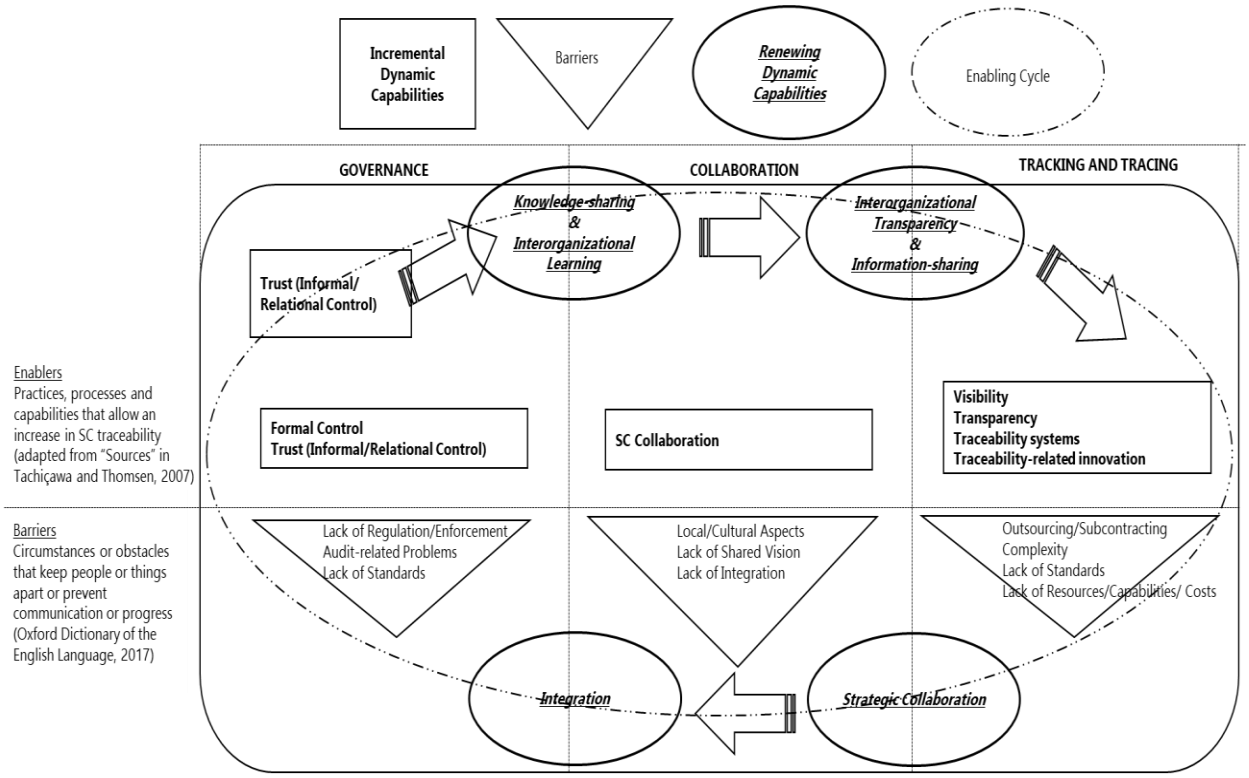


Figure 2: Traceability for sustainability cycle adapted from Garcia-Torres et al. (2019)

As illustrated in Figure 2, this framework outlines multitier SCs coupled with three dimensions – (i) governance, (ii) collaboration, and (iii) traceability and tracking – to improve sustainability development in the business management field (Garcia-Torres et al., 2019). Gereffi (1994, p.90) defines *governance* as the "authority and power relationships that determine how financial, material and human resources are allocated and flow within a chain". Cao et al. (2010) define *collaboration* as two or more autonomous firms that form long-term relationships and work closely to plan and execute supply chain operations to achieve common goals, thereby reaping more benefits than if acting independently. Ajana et al. (2011) highlight the *tracking and tracing* dimension as it comprises the conditions, organizational practices, processes and mechanisms required or directly involved in facilitating real-time tracing and monitoring of products and their history throughout the supply chain.

Frazer et al. (2020) rebrand the above traceability for sustainability framework as *transparency for sustainability* (TfS). This is based on (i) the objective is greater transparency, and this is accomplished by tracing the products and their components from SC backwards and (ii) the operation of multitier sustainable SC transparency requires the alignment of empirical and real-world experiences. According to Muller et al. (2020), digital data sharing and collaboration across firms is a new way of managing SC, where IT links with lead firms and N-tier suppliers are optimized, and data sharing can be automated. Managing the MTSSCM with a higher level of transparency as a core is critical to dealing with increasing sustainability awareness and global chain disruptions (Sauer and Seuring, 2019). Compared to global supply chains, Nandi et al. (2021) emphasize that collaborative technologies with localized systems are becoming more resilient, transparent, and sustainable. It is essential to have good governance and collaborative mechanisms among stakeholders in the supply chain to overcome the institutional pressures and challenges such as good/dark side of supply chain practices used by factory management of multitier suppliers. The system includes institutional players such as buyers, auditors, and inspectors (representatives of policy makers/regulators) who demand sustainability practices (Nath and Eweje, 2021).

2.3. Research focus

The existing studies on the MTSSCM provide a more theoretical perspective (e.g., Fraser et al., 2020; Garcia-Torres et al., 2019) of the TfS framework to focus on the outcomes. This study elaborates on the mechanisms of developing organizational competencies in dealing with the multitier supply chain network using semiconductor supply constraints with the help of TfS framework dimensions such as governance, collaboration, and transparency. While Zehendner et al. (2021) provide the electronics industry multitier supply chain sustainability tensions perspective, this current study aims to develop of competencies to deal with MTSSCM in the global automotive industry. This will allow automotive practitioners to integrate the research findings into their organization's business process and to manage their parts supply in a disruptive manner. Our study focuses on operations of multi-tier supply chains and provide a framework to consider at the time of supply-demand crisis. The findings of our study will help practitioners identify the necessary competencies as per the TfS framework to ensure that automotive firms may establish MTSSCM as a framework to increase supply chain transparency for sustainability. Furthermore, the research questions also investigate the competencies necessary to deal with a part of the supply chain crisis scenario.

3. Research methodology

In this research we use multi-method research namely case study interviews, data from observation study of the automotive company and from focus groups. Accordingly, we have framed the research design and data analysis to unveil the research questions. In this aspect, competencies are identified as very vital in organization to adapt the supply chain transparency for sustainability – to manage both - the long-term SC risk management and short-term SC crisis situations. This is further discussed in this section.

3.1. Research design

By examining information provided by global automotive firms and analyzing a TfS framework, our study has supported enhancing the required competencies for MTSSCM. We evaluated the operational MTSSCM business model to manage SC risks from three automotive OEMs based in the USA, Japan, and Germany, respectively. We chose these reputed automotive brands as these OEMs (hereafter focus firms) belong to the top three vehicle manufacturers from the respective markets. We employed an intervention-based research method with an abductive reasoning mode

to generate insights from the TfS framework and the real-world global automotive OEM practices to develop the required MTSSCM competencies (Chandrasekaran et al., 2020; Coughlan et al. 2016). Intervention-based research helps to create new approaches and strategies from the empirical research to test theories through practices (Oliva, 2019). This approach can either be used to test the existing theories or it can be foundation for development of a theory.

Furthermore, the study includes the integration of cross-case study and design science research process approaches utilizing context-intervention-mechanism-observe (CIMO) logic to formulate design propositions from the insights from the focus firms regarding the expected outcome (Kaipia et al., 2017). In Figure 3, we illustrate a research framework integrating theory and evidence using intervention-based research methods.

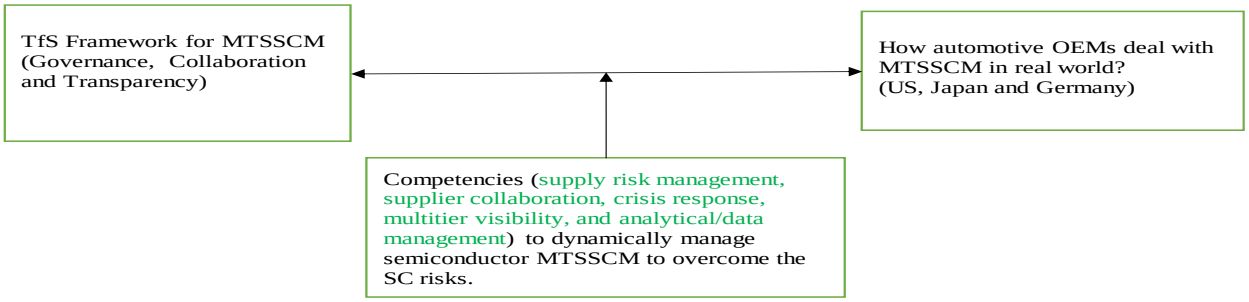


Figure 3: Intervention Mechanism

Figure 3 highlights the theoretical TfS framework and practical situation in automotive OEMs dealing with MTSSCM. This is to build or develop required competencies needed in the organizations to overcome the supply chain risks both for the long-term supply risk management (SRM) and/or the short-term SC crisis response management (Siems et al., 2021; Wu et al., 2021). The required competencies to manage the MTSSCM to overcome the SC risks are further investigated by researchers using an integrated case study and design science research process as shown in Figure 4. This has been communicated to the case company to evaluate their process improvement (performance) after observing the competencies, namely supply risk management, supplier collaboration, crisis response, multitier visibility, and analytic/data management (Anand et al., 2021).

We have chosen a qualitative cross-case study approach with multiple embedded analysis units as it is suitable for studying complex phenomena and their context in the real world (Yin, 2014; Voss

et al., 2002). It has been approached in two phases. In phase A, as shown in Figure 4, we address the present concerns of how the multitier sustainable supply chain management (MTSSCM) process using the semiconductor supply chain is being managed in three global automotive firms with the help of case study interview script. This is the context ('C') step. Comparing the practical evidence using intervention-based research (as shown in Figure 3) with the TfS framework (theory) to analyze the required competencies is the intervention ('I') step. In parallel, it generates the required mechanisms to resolve the concern. This is the mechanism ('M') step. The insights are then observed with the help of a cross-functional focus group and in-depth interviews with clear outcomes on how the firms can benefit from MTSSCM competencies. This is the observe ('O') step. The outcomes are further evaluated to revisit the required mechanisms to develop the best practice on managing the supply constraints and recommend that it is introduced in the firm. Based on the actual practices adopted to manage the semi-conductor MTSSCM, we found that aggregated mechanisms are common across all OEMs although the maturity level varies. Hence, in phase B, only the US automotive firm is chosen to revisit the proposed MTSSCM mechanisms to measure its outcome prior to development of the design propositions assuming that it will not generate any biased outcome. This is elaborated further in section 5.

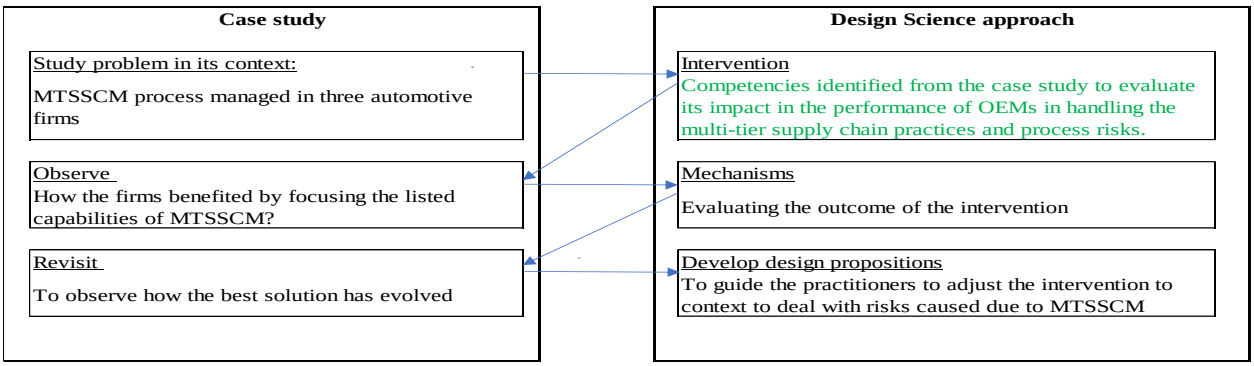


Figure 4: Integrated research process using case study and design science approach

Figure 4 highlights the research process followed in this paper. As part of the intervention phase in CIMO, to evaluate the role of interventions, detailed study was conducted on the current multi-tier supply chain competencies followed by global OEMs and TfS framework. This has shed light on the need for stronger supplier collaboration, multi-tier visibility requirements by enhancing SRM organization for long-term risk management and SC crisis management for short-term crisis with the help of enhancing the data analytical capabilities. The intervention 'competencies'

especially collaboration, crisis response and visibility showed high level of process improvement in OEM, enhancing the supply chain transparency across the tiers for the business sustainability.

We have selected the focus firms in a way that aligns with achieving our research objective. We used a purposive sampling method. OEMs chosen for this study operate in a similar setting (mass volume vehicle manufacturers) but have differing characteristics such as product type and sourcing footprints thus allowing for an interesting cross-case study analysis in the form of outcome evaluation (Barratt et al., 2011; Miles and Huberman, 1994) for semi-conductor MTSSCM competencies.

3.2. Data collection and analysis

The study uses multi-method reserch for collecting and analyzing data, as shown in Table 1. The current semiconductor supply crisis was discussed in an initial meeting with representatives from three global automotive OEMs to understand how the focus firms were managing the shortage situation in the post-COVID-19 stage. A lack of sufficient chips resulted in both production losses and plant shutdowns due to supply impacts on both new and current products. As a result, shipping container shortages were experienced as automotive firms did not release their inventory of non-semiconductor materials. Subsequently the business performance of the entire end-to-end supply chain was negatively impacted.

Table 1: Data collection and analysis

Sl. No	Phase	Automotive Firm	Meetings	Researcher's role	Informants	Data
1	Review and study the MTSSCM using semiconductor SC in the context of current crisis to develop longterm competencies	USA OEM Germany OEM Japan OEM	Early planning review to understand focus firms action in managing the global semiconductor shortage situation to meet the production demand.	Meeting facilitators, and capturing the meeting minutes.	Supply risk management (SRM), production control and logistics leads SRM, production planning and logistics leads SRM, quality, logistics, engineering and finance leads	No data collected or required in this phase
2	Designing a cross case-study questionnaire in collaboration with automotive practitioners	USA OEM Germany OEM Japan OEM	Meeting for designing the questionnaire in association with TfS framework and alignment to participate.	Facilitators	SRM, logistics, supply chain, production control and engineering leads SRM, logistics, quality, production planning and engineering leads SRM, quality, logistics, finance and engineering leads	Modularity strategy, SRM objectives & governance reviews, multitier supplier collaboration, visibility and transparency tools practiced across multi-tiers to track order, part and payment flows, risk and mitigation plans to execute production plan against each chip affected commodities, etc.
3	Observing the discussion outcomes	USA OEM Germany OEM Japan OEM	Three cross functional focus-group reviews to know the semiconductor part supply impact for both new and current product portfolio. Three in-depth interviews using questionnaire in Appendix A with SRM experts and business consultants who lead the functional review to secure part supply.	Observers, interviewers, and collecting the review outcome.	SRM, logistics, supply chain, production control, engineering and IT leads & business consultant. SRM, logistics, quality, production planning, engineering and IT leads & business consultant SRM, quality, logistics, manufacturing IT, finance and engineering leads & business consultant	Current model: Product wise operating plan impact for next 6 weeks on rolling basis, part allocation for priority models, inventory and premium freight impact, finalising the non-production days, supply chain value stream mapping for the affected commodities and other alternate options. New model: New technology and supply base associated with the forward model, development of supplier mapping data across multitiers, investigation of alternate containment actions (e,g,, product feature amendments, timing deferral, etc.), budget requirements, and profit impacts.
4	Revisit to observe how the recommended solution evolved	USA OEM	Focus group review with business consultant and SRM lead	Interviewers	SRM, supply chain, production control and scheduling leads & business consultant.	Material cost, freight and inventory impact for the products made for 6 months period on account of the MTSSCM challenges versus actions proposed to reduce the impact.

Interviews are an effective way to gather empirical data, providing diverse perspectives and mitigating potential biases (Eisenhardt and Graebner, 2007). With the help of the focus firms, TfS framework dimensions – governance, collaboration, and transparency – were discussed critically. We conducted six semi-structured interviews between January 2021 and April 2021, which included three focus groups and three in-depth interviews with open-ended questions. As shown in Table I, from each OEM, around six cross-functional practitioners took part in the focus group discussions and two of them participated in further in-depth interviews. Informants are highly experienced in their respective fields. The intention was to comprehend the similarities and differences between control modules for current and new products and to understand the role of supply risk management (SRM) functions in firms in developing an analytical capability. These competencies are associated with predicting supply chain risks, approach, and governance mechanisms for OEMs in collaborating with multitier supply chain networks, current visibility of the forecast, inventory, and early shortages, and flexibility in sourcing the commodities across tiers.

After brainstorming sessions with peers and with input from automotive practitioners from the focus firms, nine open-ended questions were formulated under each TfS framework dimension to assess their competencies to build supplier relationships and manage supply crises. The interview script is presented in Appendix A to enhance long-term competencies at automotive companies. In the case of the Japanese OEM, a translator joined the focus group and was present for the in-depth interviews. The completed interview scripts were shared with the translator to ensure their quality and that they captured the entire content of the interview questions.

We recognized the importance of building competencies for focus firms to deal with supply disruptions. This was echoed by the practitioners in the focus firms. The current and new model contents shown under the data section were observed in the focus firms, according to Table 1. Initially, we participated as observers while the interview script was prepared. Subsequently, we collected quantitative data on how the semiconductor supply crisis affected new product introductions. From the interviews, the participants evaluated such factors as delays in installation which affected launch timing and current product production gaps as a result of additional material, freight and inventory costs.

The last phase of the research was conducted for four months from May 2021 to August 2021 after the beginning of the initial intervention to study how strengthening mechanisms that were triggered from the initial intervention can improve operations. In the context of multi-tier semi-conductor supply chain shown in Figure 1 in page 4, the case firms experienced common challenges in dealing with supply risks, collaboration concerns, effectiveness of SC crisis management, and transparency gaps. Considering the same, ‘derived aggregated mechanisms’ was tested only for the US OEM firm to develop the design propositions as the nature of supply chain includes wafer production & testing, turning it to micro-processors to modules before delivery to OEMs are common for the US, Germany, and Japanese firms. Over the course of this period, the USA OEM was reviewed multiple times to gain an understanding of the MTSSCM framework and its role in governance and collaboration, as well as the track and trace mechanisms within the broader supply chain ecosystem, required by the TfS framework. The company provided data about the material, freight, and inventory impacts associated with semiconductor part supplies during this phase. Considering the common challenges, it also justifies why only the US OEM was tested in the last phase. Moreover, we collected data from our interviews with the SRM leads and business

consultant. Using the actual outcome evaluation and context analysis, we were able to formulate actionable design propositions (Denyer et al., 2008).

4. Case study – Outcomes of the MTSSCM practices

4.1. Field problem: Semiconductor supply crisis

As a result of taking the CIMO-logic into account, the first part of our study focused on the problem in its context, including both internal and external factors as well as the practitioners' behaviors that influenced the change in the cases (Denyer et al., 2008). Focus firms mapped their semiconductor multitier supply chain details to better understand who all the contract parties were and the risk profiles associated with each of them. OEMs based in the United States and Germany were directly involved in exchanging information with tier-2 suppliers via a common portal between the two parties. In addition, focus firms have engaged in lobbying efforts with governments to secure both short- and long-term automotive parts supply. Following the Tsunami and earthquake disaster in Japan in 2011, one of the focus companies expects its suppliers to maintain the stock protection of chips for about six months. As shown in Figure 1, focus firms were exploring alternative manufacturing technologies for chip production and packaging in order to increase productivity and reduce lead times. Due to the limited supply, focus firms were optimizing their product model mix in each market. These chips were allocated to make the most profitable variants. Following the focus group interactions with practitioners, semiconductor suppliers (tier-3 or tier-4) needed (i) long-term capacity forecasts of about 12-24 months and (ii) alternate processing options, such as reducing testing facility constraints for semiconductor batches. Potentially, these efforts would reduce the 'time to volume'.

The analysis of the semi-structured interviews revealed that the focus firms can benefit from semiconductor MTSSCM by improving the following competencies:

a) Operational visibility – focus firms re-examined their demand models, which include providing tier-1 suppliers with both short- and long-term forecasts. Focus companies should also gain expertise in semiconductor manufacturing processes and lead-times because this helps to determine the stock protection requirements at supplier end to meet demand.

b) Mapping multitier supply chain – the focus firms reviewed the purchasing contracts in the entire supply chain, the manufacturing and logistics lead times, and any risks associated with COVID-19 such as absenteeism, lockdowns, etc. It was observed that only some focus firms approached tier-2 or tier-3 or tier-4 suppliers directly for commercial agreements that could be maximized.

c) Risk management teams – these were formed in all focus firms to work closely with tier-1 suppliers in order to receive the supply commitments. When dealing with semiconductor allocation, the same team could be involved by considering a profitable product model and cooperating with production and sales.

d) Securing part supplies and shifting facilities – focus firms lobbied the government through their associations to ensure part supplies and ease the part shortage. Focus firms are also looking to relocate their facilities closer to the high-demand region to provide flexibility. Localization of critical commodities could also be considered at this stage.

After identifying the problem and the opportunity for improving semiconductor supply chains, the next step was to develop the right competencies and test the process.

4.2. Design of intervention

Focus firms found that the operational process enhancements adapted to address the semiconductor supply crisis were meeting the immediate sales demand. The informants were looking for better forecasting to ensure a smooth multitier supply chain operation due to the different demand and growth rates resulting from the various COVID-19 recovery actions. Drawing from Denyer et al. (2008), we also designed and implemented our intervention according to the governance, collaboration, and transparency dimensions of the TfS framework. Through the TfS Framework, we evaluated the operational practices associated with MTSSCM so that we could meet the sales demand. The intervention steps put in place the focus firms to develop the desired competencies are listed below.

- Mechanisms for monitoring geopolitical events for suppliers. These would develop manufacturing risk ratings and alternate logistics network modeling to assess the overall productivity impact.

- In the multichain supply chain, information exchange and analytical competencies are needed to ensure better supplier collaboration using short- and long-term production forecasting.
- Providing multitier visibility competency for semiconductor affected commodities and measures taken to enhance transparency. This also includes physical manufacturing site visits by tier-1 suppliers to understand the constraints and collect operational data that is managed in various IT platforms by tier-2 suppliers and beyond.
- Measures taken with the above competency steps to increase the supply crisis response flow from MTSSCM for identifying impacts and implementing mitigation plans.

4.3. Outcomes of intervention

The results of the intervention pilot indicate that the focus firms enhanced their actions and their corresponding outcomes (Kaipia et al., 2017) as follows:

The focus firms had a centralized team with expertise in purchasing, financial and macroeconomic analysis who tracked supplier production data including cycle times, capacity, and shifts in order to identify the supply risks. The team had a two-way relationship with a cross-functional team (including supply chain, logistics, engineering, quality, legal, planning, and information technology) within the focus firm to exchange information related to supplier risk-rating and mitigation plans. A structured governance review process was in place, with quarterly objectives set with internal and external stakeholders. A pyramid-based approach was used by the focus firms to assess their suppliers based on spend, critical commodities, and network importance. As for communication, periodic phone calls and surveys were conducted, but automation to reach out to suppliers was lacking. In the focus firms, there was very limited visibility into suppliers' inventories; supply risks were communicated when they arise, helping them to improve supplier performance.

The multitier visibility was collected through supplier surveys and managed using Excel with a data management solution on a contract basis. We observed that multitier visibility only existed at a rate of 10-20% for critical commodities to assess the supplier capacities and stock-on-hand details in advance of the issue. In relation to supplier evaluations, half-yearly and yearly audits

were conducted to identify gaps from a quality and delivery perspective. The purchasing and quality departments led audits regarding supply gaps. During the crisis, one of the focus firms gained priority in supply allocation because suppliers had good visibility into their demand and long-term forecasts. It was observed that firms lack shared expertise and IT solutions that allow them to engage with tier-1 suppliers and identify disruptions as soon as they occur, thus limiting the impact on production. Additionally, tier-1 suppliers were reluctant to share their supplier information since they see this as their competitive edge where focus firms potentially establish direct relationships with sub-tier suppliers. A cross-functional task force was formed by focus firms to assess production impacts, monitor supply, and engage with multitier suppliers to increase production capacity in response to supply crises.

Focus firms would become aware of the supply crisis only when tier-1 suppliers inform them of it. There was no dedicated risk management team at one of the firms, which led to significant delays in decision making, resulting in major business impact. To determine action plans for focus firms, sales forecasting data were used to determine cross-functional connections, and the same information was used in negotiations with multitier suppliers. In a few cases, these firms have common tier-1 suppliers, which means they were interested in understanding their competitors' strategies for dealing with the supply crisis.

5. Outcome evaluation and design propositions

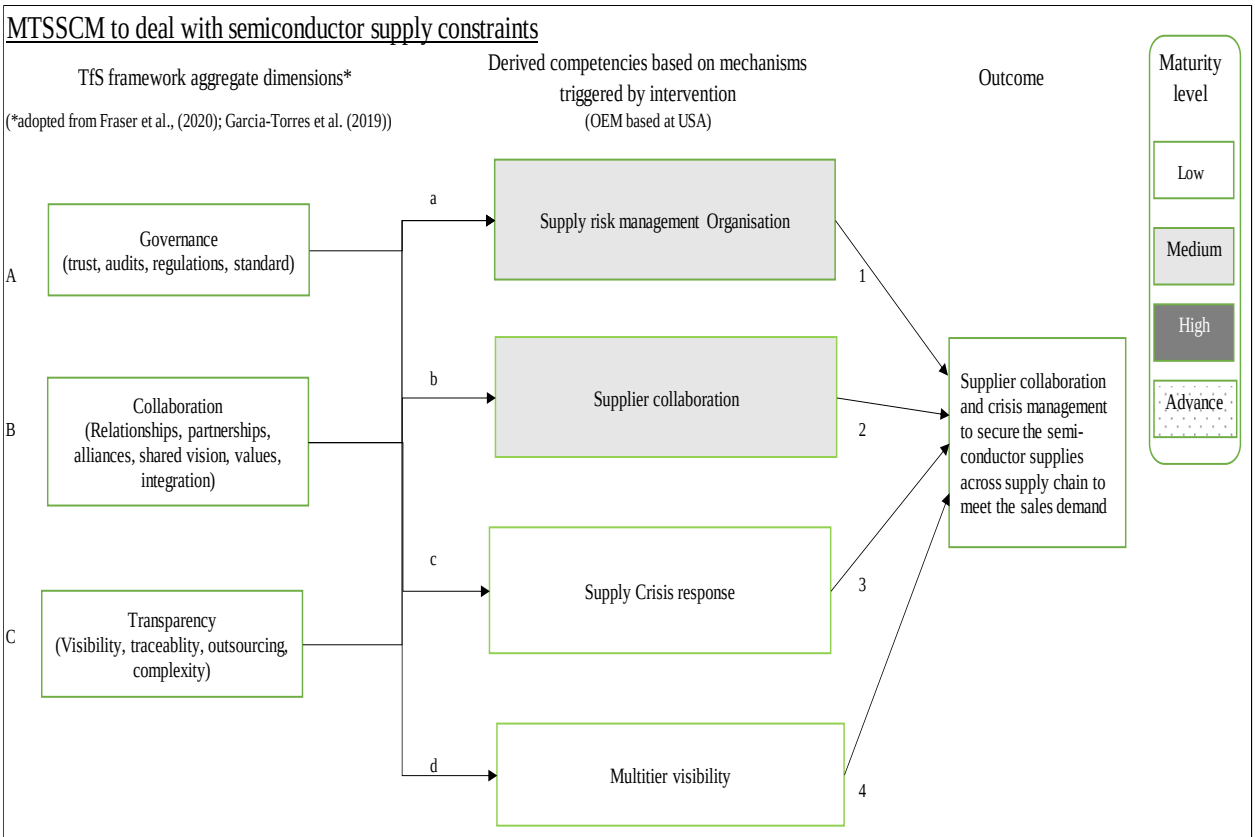
As part of this intervention-based study using semi-structured interviews, we examined the propagative mechanisms that generated business value using TfS to address MTSSCM. As a result, the competencies that can be incorporated into the governance, collaboration, and transparency dimensions of the TfS framework to improve the supply crisis situation were reviewed. According to our previous research findings in this area, most conceptual and model-based research on MTSSCM was conducted using the TfS framework (Fraser et al., 2020; Garcia-Torres et al., 2019). Nevertheless, the interactions among supply networks and their governance characteristics in multitier supply chains (Chedid et al.,2020; Mahapatra et al.,2019) are the desired competences needed in the practice.

Following Denyer et al. (2008), we can observe an intervention by introducing the required competencies in the context of the semiconductor supply crisis problem. The competencies are (i)

SRM organization, (ii) supplier collaboration, (iii) supply crisis response, and (iv) multitier visibility. The competencies have evolved from the product portfolio of the focus firms at the time of the study, which included three products from an American OEM, two products from a German OEM, and two products from a Japanese OEM. The outcome evaluation of this study used CIMO logic to identify the contextual differences and mechanisms that led to focus firms' engagement and collaboration with multitier suppliers and managed supply crises. Having identified the above required competencies (mechanisms) in the context, we then proceeded to develop actionable design propositions for focus firms, considering the necessary competencies to deal with MTSSCM to secure semiconductor supplies to meet sales demand.

5.1. Identifying the mechanisms in context

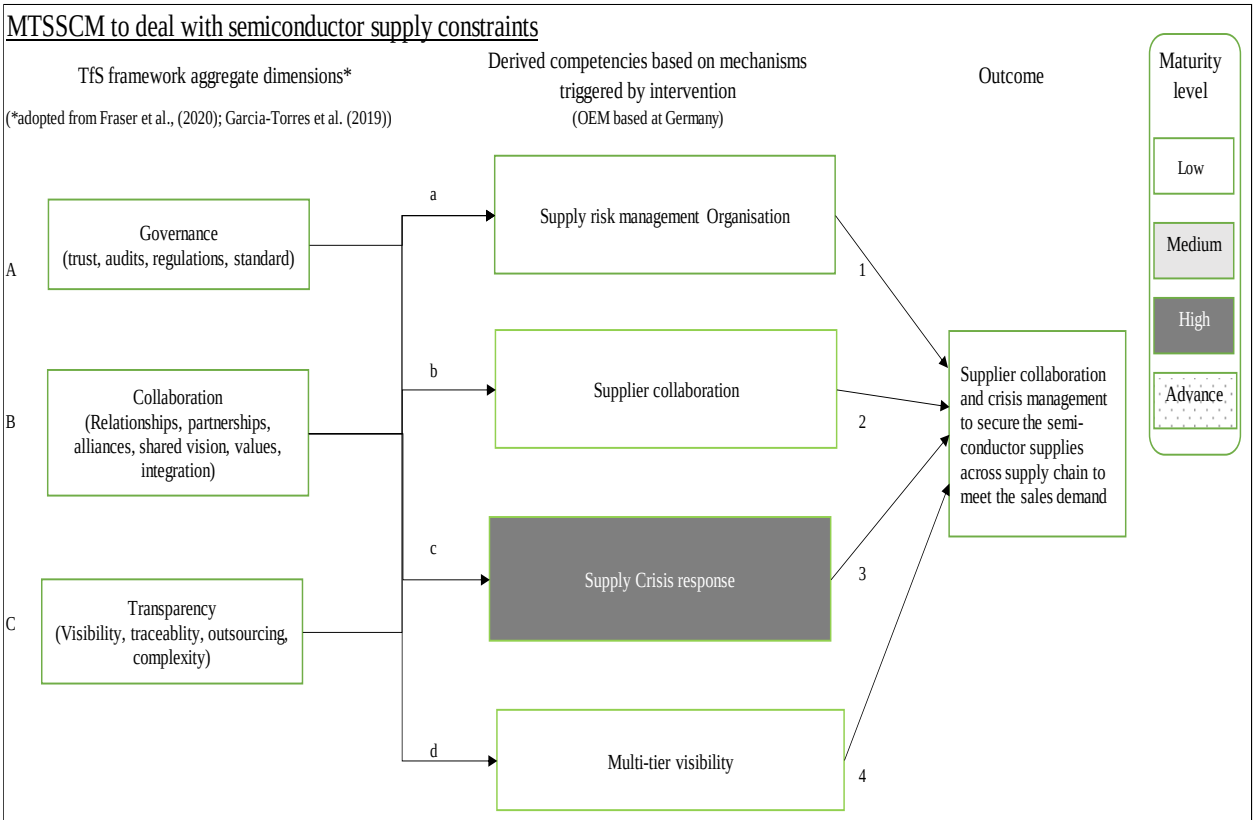
During in-depth interview stages, with the help of interview script shown in Appendix A, the cross functional team feedback from each OEMs was obtained in terms of effectiveness of ‘SRM organization’, ‘supplier collaboration’, ‘supply crisis response’, and ‘multi-tier visibility’ in dealing with supply chain risks in the multi-tier semiconductor supply chain as given in the Figure 1. On the basis of mechanisms triggered by the intervention, Figures 5, 6 and 7 summarize the outcome evaluation of the TfS framework dimensions and derived competencies. The figures highlight the maturity levels (low, medium, high, and advanced) of competencies as perceived by the SRM lead, cross-functional team, and business consultant feedback from each focus firm. We interviewed the cross functional team from each OEMs to rate their maturity levels based on their perception in securing part supplies and building the digital transformation of the supply chain. Based on this data analysis, the maturity levels were incorporated in Figure 5, 6 and 7.



TfS framework dimensions (A, B, & C) were mapped against organisational competencies (a, b, c, & d) recommended by practitioners to meet the sales demand (outcome).

TfS framework dimensions association with MTSSCM practices in supply crisis from an American automotive OEM.	**Mechanisms, rationale from automotive OEM (from case study reviews and observation)**
A) Governance was practiced effectively with suppliers to deal with semi-conductor chip supply allocation from tier-4 foundaries/ testing sites. Also, reviews were extensively conducted by supply risk management (SRM) team on daily basis at multi-tier supplier level and cross functional senior management level to align the production plan with sales demand.	1. SRM team consist of dedicated resources from cross functions to investigate the supply chain (SC) risks. SRM have structured governance framework to work closely with multi-tier suppliers to improve their performance with higher collaboration. Also, SRM team involved with senior leadership in taking the alternate sourcing decisions by bringing-out the tranparency. Competency maturity level was considered as 'medium' in comparing with best-in-class practices based on practitioners input from the case-study.
B) Collaboration was observed in dealing with supply constraints and to develop alternate plans within OEM and across multitier suppliers. SRM team having good accessibility to reach with senior leadership both at OEMs and suppliers. Drive towards standardization of chips, shared vision among multitier suppliers and OEM, and stronger relationships were practiced.	2. Supplier collaboration was handled using the regular periodical surveys, through reviews and phone calls. Also, deep engagement with suppliers across supply chain to know the supply constraints in advance. An integrated team (OEM and suppliers) develop a problem statement to take corrective actions. Considering the production demand regular supplier site visits were practiced to secure the production capacities at suppliers end. Competency maturity level was considered as 'medium' in comparing with best-in-class practices based on practitioners input from the case-study.
c) Transparency were good in terms of dealing with complexity and identifying potential outsourcing. However, lack of detailed information beyond tier-1 suppliers impacted in taking agile decision making in terms of capacity availablity and managing allocation. Visibility and traceability factors requires 'step-change' improvement as per the observation.	3. Crisis response was managed via cross functional engagement within OEM and supplier stakeholders. Also, competitors impact assessment were performed using benchmark studies in securing the supplies. SRM team leads in developing the mitigation plans and align swiftly in the senior management reviews to manage the production demand. Assessment of retrofitment of modules or parts without impacting product quality was considered in finalizing the production plan. Competency maturity level was considered as 'low' in comparing with best-in-class practices based on practitioners input from the case-study. 4. Multi-tier visibility was observed as a challenge as the OEM have limited visibility beyond tier-1 supply. Similarly system driven traceability require more focus as most of the assessment is currently done using excel template for the supplies beyond tier-1. Analytical and data management capabilities are the primary enablers to improve the overall MTSSCM. Competency maturity level was considered as 'low' in comparing with best-in-class practices based on practitioners input from the case-study.

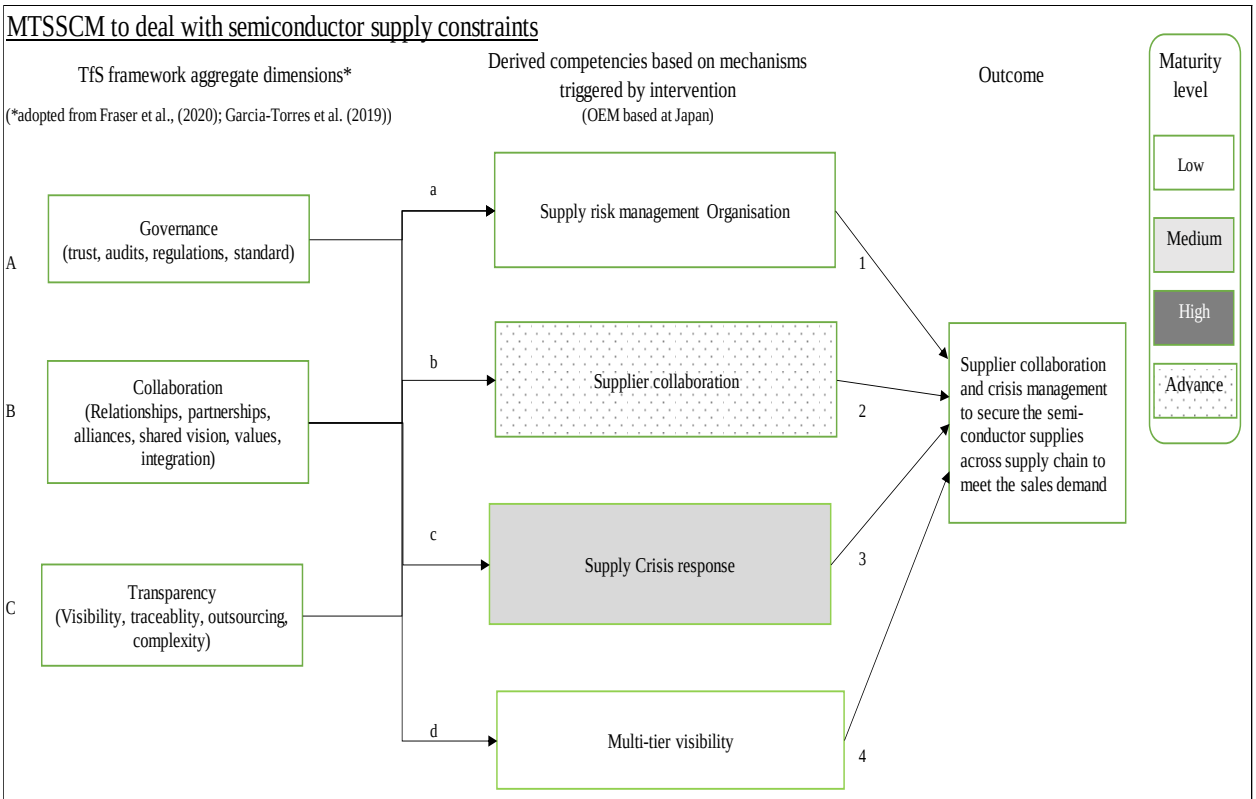
Figure 5: MTSSCM constraints – Outcome evaluation for an American case



TfS framework dimensions (A, B, & C) were mapped against organisational competencies (a, b, c, & d) recommended by practitioners to meet the sales demand (outcome).

TfS framework dimensions association with MTSSCM practices in supply crisis from German automotive OEM.	**Mechanisms, rationale from automotive OEM (from case study reviews and observation)**
A) Governance process with internal functions within OEM and external supply base has been followed to deal with semi-conductor chip supply allocation especially from foundaries/ testing sites. Special daily reviews at senior management level to adjust production requirements, alternate containment options such as retrofitment possibilities without impacting the quality level, etc. has been reviewed.	1. SRM team consist of dedicated resources to investigate the supply chain (SC) high-risk situations in the plant location. Extended team does macro-economic analysis for geopolitical risks in a central location. Lower penetration level observed in terms of multi-tier suppliers data for critical commodities, practitioners inclined to improve performance with higher supplier collaboration. Competency maturity level was considered as 'low' in comparing with best-in-class practices based on practitioners perception from the semi-structured interviews.
B) OEM has collaboration ability to access the supplier information through continuous engagements across multi-tier supply chain network. Also, OEM closely monitors the supplier quality and processes, however inventory visibility is available only for critical commodities (on request basis).	2. Supplier collaboration was handled by purchasing function who leads in managing supplier relationships. Purchasing continuously engage with suppliers to manage supply and identify sub-tier suppliers using the surveys, and phone calls. OEM has maintained a database of sub-tier suppliers gained through tier 1 supplier engagement. This database is shared with production. Competency maturity level was considered as 'low' in comparing based on practitioners perception.
c) OEM has been able to achieve 100% transparency on continuous basis into inventory levels and future supply. Shared IT and ERP systems were used to engage and share the information. Multi-tier supply base able to report performance indicators on pre-decided dates to identify support requirements.	3. Crisis response was managed via cross functional engagement within OEM and supplier stakeholders. Tier 1 supplier alerts the OEM regarding crisis. OEM Closely monitors supplier quality & processes for any potential issue. Supplier site visits also conducted to validate the crisis before making decision. Production capacity requirements is provided at OEM facilities as well. Competency maturity level was considered as 'high' based on practitioners perception.
	4. Multitier visibility was observed as a challenge as the OEM have limited visibility beyond tier-1 supply. Purchasing and production team from focus firms have visibility into suppliers' manufacturing processes. It closely monitors the processes to gain first-hand information on potential supply issues. OEM has visibility into inventory levels and capacities of tier-1 suppliers on case-to-case basis. Competency maturity level was considered as 'low' in comparing with best-in-class practices based on practitioners input from the case-study.

Figure 6: MTSSCM constraints – Outcome evaluation for a German case



TfS framework dimensions (A, B, & C) were mapped against organisational competencies (a, b, c, & d) recommended by practitioners to meet the sales demand (outcome).

TfS framework dimensions association with MTSSCM practices in supply crisis from Japanese automotive OEM.	**Mechanisms, rationale from automotive OEM (from case study reviews and observation)**
A) Structured governance process with supply base across multi-tier network has been followed to manage semi-conductor chip affected module supply. Each review - at daily/weekly/monthly - follows with an set-agenda with an expected outcome. Mostly in daily reviews, production plan requirements, delivery options to dealers, alternative transportation options, etc. considering semi-conductor associated module supply situation has been reviewed and aligned.	1. Production buyers part of purchasing department are responsible to continuously connect with suppliers and manage supply. Regarding strategic suppliers, OEMs operate with "Champions" model to build the business relationships. It was observed that meeting cadence, attendance tracking, assignments and minutes recording were very systematic. Governance process across supplier base is strong with manual interventions. Competency maturity level was considered as 'low' in comparing with best-in-class practices based practitioners update from interviews.
B) OEM has an extensive supplier collaboration model across multi-tier network with **business continuity plans (BCPs).** This helps priorities regarding semiconductor supply allocation as soon as the disruption occured. This collaboration effort was seen as a primary differentiator in comparing with other focus firms in this study.	2. Supplier collaboration was handled in such away using BCPs where suppliers were required to make stock protection quantities (inventory) of the critical commodities. This moving away from just-in-time (JIT) process of lean manufacturing, which means the OEM is able to strike the balance between lean and resilience. Also, OEM has a global platform where multi-tier supply base register and share critical information (Cycle Time, production shifts etc.) that leads OEM to identify supply chain issues. Competency maturity level was considered as 'advanced' based on practitioners perception in comparing with other focus firms in this research study.
c) OEM has been able to achieve 100% transparency with multi-tier supply network in engaging with BCPs, forecast visibility and stock protection communication through their schedules. Also, it was observed that supply complexity is managed well with process transparency across other supply eco-system stakeholders such as logistics service providers, carriers, etc.	3. OEM has been managing crisis response through monitoring the disruption events that can impact production, such as natural disasters, fires, financial issues and labor issues, etc. In case of semiconductor supply, OEM defined all components and raw materials that are dependent on production as mission-critical parts. To expedite the supplies inspections and countermeasures are continuously implemented around the world with its affiliates. In addition, yearly supplier evaluations conducted using surveys to minimize the supply risks. Competency maturity level was considered as 'medium' in based on practitioners perception observed from interviews.
	4. Multitier forecast visibility was observed as OEM has been sharing the 12-to-18-month forecasts twice in a year to let suppliers model their production capacity and let OEM know of any constraints. Timely stock protection of chips ensured OEM has 2-6 months of inventory at tier 2 or tier 3 supplier end which has helped OEM to reduce the overall shortage impact in the current semiconductor crisis. Most of the data collection work is led manually, hence the practitioner feedback indicates that more work to be done to improve the visibility level in terms of stock movement situation across the entire chain. Hence, competency maturity level was considered as 'low' in comparing with best-in-class practices based on practitioners input from the case-study.

Figure 7: MTSSCM constraints – Outcome evaluation for a Japanese case

Evaluation results indicate that all TfS framework dimensions – governance, collaboration, and transparency – have a strong association with developed competencies. Our intervention also raises a theoretical TfS extension in terms of how the multi-tier visibility mechanism contributes to the agile decision-making process across the supply chain using analytics and data management competencies to improve the supply condition.

Accordingly, the first identified mechanism of the outcome evaluation, supply risk management (SRM), explains how the target firms may further reap the benefits of digitalization. The centralized SRM team can enhance focus firms competencies further such as (i) monitoring supplier performance, compliance, brand and strategic risks, (ii) tracking geopolitical risk indicators and events which can affect the multitier supply chain, (iii) real-time tracking of suppliers, production locations, logistics, air and sea ports, among others, via information exchange, (iv) integrating data management platforms used by multitier suppliers to collect and manage information, and (v) identifying the critical market segments to monitor for available short- and long-term capacity. To obtain the response, we explored with the focus firms the identified mechanism of an SRM organization, as well as the use of digitalization competency in engaging with multitier supply networks. The semiconductor crisis presents an opportunity to enhance the data-sharing and management processes to handle the complexities of the supply chain. This accorded with Keller et al.'s (2021) findings from German firms, which found that digitalization decreases the use of informal governance mechanisms, but also calls for further engagement regarding supply network disruption. The required skill with digital competencies is in line with Paolucci et al.'s (2021) findings from the Italian automotive industry where digital transformation and governance mechanisms can coexist.

Collaboration among multitier supply networks is identified as the second mechanism or competency requirement. The Japanese OEM firm is on the advanced level as shown in Figure 7, where business continuity plans (BCPs), long-term forecast visibility for 12-18 months, and stock protection for two to six months during times of supply crises are implemented effectively. The Japanese OEMs also led the efforts to build good financial ties between banks and suppliers. Although the production operations are responsive to demand, the semiconductor supply crisis affected schedule stability. This mechanism allowed all focus firms to update revised forecasts faster, thereby avoiding stock-out risks. In light of the improvement and best practices from Japanese OEMs, US and German OEMs were encouraged to prioritize the supply assurance,

cost reductions and chip stock protection across multitier supply networks. The results of the interviews also suggested that the over-simplified use of resources for collaborative decision making based on the stock movements helped the US and German focus firms make revisions to their initial forecasts for the next three to six months. As a result, the working capital for all non-semiconductor parts was reduced to meet the production rate. This is in line with integrated innovation strategies in the German automotive industry in exchanging knowledge on a timely basis (Wilhelm and Dolfsma, 2018).

The third mechanism involves managing supply-crisis responses from a multitier supply network. A cross-functional team led by SRM evaluated the supply status for the USA OEM, while the German OEM engaged multiple suppliers to analyze the supply reality of semiconductor-related modules and components. All focus firms engaged in identifying the business impact associated with supply crisis during product launches, using centralized data management for more collaborative efforts. All focus firms' practitioners acknowledged the importance of data analytics and management for forecasting supply and improving responsiveness for both current and future product models. Japanese OEM practitioners talked about the efforts taken by tier-1 suppliers in terms of product modularity and supply chain integration, particularly in regard to semiconductor supply-affected commodities for expedited delivery. Therefore, this mechanism supports the findings and relationship of supply chain integration with product modularity, as well as the uncertainty of NPD performance (Lau et al., 2010; Zhang et al., 2021).

Multitiered supply visibility is the final mechanism. We observed that in all of the focus firms, the system visibility only extends to the tier-1 suppliers. Stocks on hand at tier-1 and other parts supplied by multitier supply networks are managed based on the feedback for critical commodities. To manage the semiconductor supply crisis across multiple tiers of supply networks effectively, practitioners from all these companies agreed that interorganizational information systems will be essential to process alignment and adaptability. By having a strong business intelligence dashboard, they can keep track of the part flow as it relates to the latest order flow and stock on-hand across each stage of the supply chain. For the focus firms, this competency level is deemed low. The results are in line with leveraging information systems across supply chains for better integration and compliance with Industry 4.0 (Pu et al., 2019).

The concentrating mechanism requires focus firms to identify the optimum situation in managing the MTSSCM to achieve a better pay-off by adapting to the TfS framework. Such competencies ensure that the planning resources are efficiently utilized. Adding of resources may be required to establish and manage the effectiveness of digitalization, data analytics, and data management among the supply base since human decision making remains central to successful management (Kaipia et al., 2017).

5.2. Actionable design propositions

From the interview script, it is clear that the focus firms in this study experienced different outcomes when introducing the dimensions of the TfS framework in order to enhance MTSSCM competencies. In the observed case outcome, there is multitier visibility along with long-term forecasts, as well as supplier collaboration along with business continuity plans to safeguard chips during crisis periods to satisfy sales demands. Figure 1 illustrates that – given the semiconductor manufacturing lead times and supply chain intervals are long – it makes sense to improve the transparency among multitier supply networks for greater sustainability. This supports the academic suggestion in Dubey et al. (2020) that upstream supplier visibility can contribute to sustainable performance improvement. Based on this, we make the following first proposition:

The supplier from a multitier supply network benefits from transparency in terms of visibility, as well as being able to adapt to a digital transformation. It is essential to improve response by making decisions quickly to support schedule amendments from OEMs with a shorter lead time in order to meet customer demands.

As a result, if we extend the proposal to a new model introduction, the TfS framework can be considered for planning the supply network that can reduce the supply chain risks due to technology additions and resources being planned by focus firms. The TfS framework is thought to significantly reduce sustainability risks by introducing supplier collaboration and operationalizing it in MTSSCM (Fraser et al., 2020; Garcia-Torres et al., 2019). This research was able to support these results by introducing the right competencies to reduce supply risks by using multitier semiconductor supply chains. The focus firms needed to understand the competencies

that would be required to adapt the TfS framework for the long term as well as the immediate competencies required to handle the semiconductor supply crisis in the short term to meet demand. On the basis of our contextualized understanding of how the SRM organization leads to supply crisis response, we think it is well suited for short-term management. Our findings indicate that supplier collaboration across a multitier supply network is a primary differential mechanism adopted by Japanese OEMs compared to the other two OEMs, such as BCPs and stock protection.

To extend knowledge on this area, supplier collaboration requires close coordination across the organizational functions within and between firms in the supply chain (Schneeweiss, 2003). Despite a lack of clear explanation, the academic literature on collaborative planning in supply chains acknowledges that collaboration is valuable (McCarthy and Golicic, 2002). Our study attempts to fill the gap by analyzing actual practices employed by practitioners when dealing with critical part commodities. After the Japan disaster in 2011, Japanese OEMs implemented a business continuity plan in which suppliers of about 500 critical commodities, including semiconductors, are required to maintain stock protection quantities of two to six months' supply. We find that criticality cannot be applied to all commodities, and that constant assessment of global material supply constraints is necessary. Son et al. (2021) highlights the importance of buyer-supplier bridging ties to improve catastrophic supply chain disruptions and supply network changes in Japan. This leads us to our second proposition:

By enhancing supplier collaboration, OEMs provide long-term forecast visibility, emphasize supply assurance, and support the supply base with necessary financial ties with banks in order to safeguard critical commodities. To reduce or prevent the uncertainty and sustainability risks, there is a need for a change management process across multitier supply networks.

We also propose strategies for modularity in the upstream product introduction processes to consider the reduction of complexity in buildable configurations and to push for more commonality to optimize the resources for complex supply chains. This is in line with the principles of RBV as the case considered in this article uses competencies and resources of all partners involved in the supply chain processes. The advancement of data analytics and management competencies in terms of risk management allows for greater transparency in dealing

with global supply shortages which is very much supporting the philosophies of RBV. As part of the research context, we first discussed first the MTSSCM competencies needed using the TfS framework dimensions – governance, collaboration, and transparency – in the focus firms to meet production demands and introduce new products. In the second part, we identified four mechanisms based on the competency areas of OEMs that use the semiconductor supply chain to deal with the supply crisis with the help of digital transformation. These mechanisms address the research questions in the section 1. To ensure the data reliability of the collected data as shown in the section 3.2., our research findings were shared to all the case firms along with design propositions and received feedback from OEMs on the impact of developed interventions in the multi-tier supply chain process improvement. Especially, the time taken to arrive at decisions to overcome production shortage risks due to semiconductor supply chain risks, has been improved by enhancing the interventions (competencies). This effort led to the robustness of the research work, adding value to the actual practices of OEM in MTSSCM.

6. Research conclusions, limitations and future research

Based on an intervention-based study with design science approach, this research looks at the mechanisms empirically. It aims to determine how MTSSCM competencies can be applied in the automotive sector using the TfS framework. Our study identifies four mechanisms that enable OEMs to achieve higher levels of competence when they bring governance, collaboration, and transparency to the MTSSCM process. The mechanisms are (i) SRM organization structure, (ii) supplier collaboration, (iii) supply crisis response, and (iv) multitier visibility. The mechanisms are part of the operations management concepts of sustainable production and controlling supply chain risks in the MTSSCM process by improving analytical and data management competencies. Consequently, analytical and data management is added as the fifth competency in Table 2 to compare the current state among focus firms as it allows the firms to follow digital transformation. According to practitioners at the focus firms, Japanese and German firms are more committed to digital transformation than American firms are. We also find that the TfS contextual dimensions are described by the semiconductor supply crisis where such mechanisms can be applied by automotive firms in MTSSCM situations with volatility in demand. As shown in Figures 5,6 and 7, both SRM and supply crisis response teams are highly associated with TfS model dimensions

such as of building governance, collaboration, and transparency across multi-tier supply chain stakeholders to bring timely communication associated with data or information flow, physical material flow and payment flows. This is to improve the MTSSCM competencies in terms of supply chain visibility across the supply chain tiers to assess the flows on real-time basis to make agile decisions.

Table 2: Comparison of competencies among focus firms

No	Competencies	American OEM	German OEM	Japanese OEM
1	SRM organization structure	a) 5-10 Member SRM Team. b) Financial and geopolitical risk ratings are shared with multitier supply network.	Centralized 5-10 member SRM team only for high-risk situation - specialized in products and commodities.	a) No dedicated SRM Team. b) Purchasing buyer is responsible for managing supplier risks and relationships
2	Supplier collaboration	a) Annual surveys with tier-1 suppliers to identify the supply constraints. b) Site visits to know the issues at ground.	a) Close monitoring of supplier quality and processes. b) Stock at supplier end visibility only for critical commodities.	a) Provides 18months forecast visibility twice a year to multi-tier supply base. b) business continuity plan requires supplier to follow stock protection
3	Supply crisis response management	Cross functional team (CFT) form "Supply war rooms" to know the production impact and implement action plan	a) Executive level visit to supplier sites to validate the risks and develop response plan. b)Allocates capacity at OEM facilities to support the multitier supply network.	a) CFT to help supplier irrespective of contractual obligations b) Daily production status report to monitor the supply status
4	Multitier visibility	Visibility into only 10-20% of tier-1 suppliers through prior crisis management experience	Purchasing maintain a database of sub-tier suppliers for critical commodities- shared with production on need basis.	Multitier visibility on critical commodities through supplier surveys to identify the bottleneck suppliers.
5	Analytical and data management capabilities	a) 3rd party data management tools for multi-tier supplier data. b) In-house tools to analyze financial risks of suppliers.	a) Shared portal for shipment data providing near term transparency. b) Macro-economic analysis conducted on geopolitical risks	a) Shared database to manage supplier productivity data. b) Analyzes gathered data to identify production related risk suppliers.

Maturity Levels ----------->> Low Medium High Advance

The data collection and analysis phase also brought the interference of building and sustaining the desired competencies for organization to deal with multi-tier semiconductor supply chain along with the analytical and data management capabilities. Maturity levels indicate the need for further interventions in auto OEMs in the selected areas to strengthen it further. To measure the effectiveness, this research study has explored - how the recommended solution was evolved through testing of the US OEM.

A number of research articles have examined the practices and procedures associated with TfS dimensions to use them in the supply chain. Moreover, these show that firms require more resources when their business situations become more complex. By emphasizing the importance

of competencies and comparison among developed markets' focus firms, as shown in Table 2, robust planning and decision-making efforts can be developed. This is a unique contribution to the literature on bridging the gap between developed and developing markets to meet the sales demand in the post-COVID-19 era. The design proposals focus on how to regulate the planning aspects to manage the crisis both at OEMs and suppliers in multitier supply networks in order to achieve the desired outcome. The findings of this study are in agreement with Fraser et al. (2020) regarding the adoption of the TfS framework to the MTSSCM process and they provide the empirical evidence on the need to adjust the processes and improve competencies to support sales. In addition, these results add to the findings of Lorentz et al. (2021) regarding the necessity for procurement digitalization with respect to context, interventions, and mechanisms that add to the benefits. Multi-tier visibility contributes to agile decision making in such a way that if there are production or supply issues impacts anywhere in the supply chain (due to shortage or COVID outbreak– decisions can be taken in terms of alternate materials and resourcing actions. This will avoid any delays to ensure the production continuity.

The focus firms have identified a lack of visibility into multitier networks as a significant challenge. According to the semiconductor supply chain study, automotive practitioners in developed economies are looking to leverage information technology (IT) vendors to develop data models and necessary tools, along with multitier supply network engagement, to enhance supply chain transparency. Pournader et al. (2020) explore the sustainability-related supply chain risks that require organizational attention which supports the mechanism of SRM formation to deal with semiconductor MTSSCM. The automotive industry is focusing on digital transformation to improve automotive supply chain resilience to improve supply chain performance with the help of digital supply chain technologies in the post-COVID-19 era (Balakrishnan and Ramanathan, 2021). This research confirms that such technologies need to be introduced across multitier supply networks to gain visibility, particularly when dealing with post-pandemic scenarios.

To support our research, we conducted the semiconductor study over a year, and the design of the research along with mechanisms was based on the practices followed by focus firms, as shown in Table 2. Considering the supply crisis, special emphasis was placed on the way that Japanese OEMs managed the supply compared to the other two OEMs. By introducing the recommended mechanisms to improve the semiconductor supply chain, the huge revenue loss expected by global automakers in 2021 could be offset. The loss is estimated at around US$210 billion (Auto

Economic Times, 2021). Furthermore, this approach and mechanisms are potentially replicable to the planning of electric vehicle battery supply chain multitier networks for managing resources efficiently (Kalaitzi et al., 2019). Assembling batteries, manufacturing batteries, and mining precious metals all come under this category. A further research and field test is needed for the battery supply chain to determine whether there is a need for any additional design proposals regarding the requirement for unique competencies. Thus, the multitier framework proposed in this design science research will be useful to global automakers to plan their supply chains and improve overall operational performance.

This research paper only considers the automotive semi-conductor shortage situation, which may be resolved eventually when there are more installed capacities. Therefore, it is unclear whether the proposed responses will result in long-term solutions. Further modifications may be needed to revisit the TfS framework. The present research paper addresses only the automotive side of the supply crisis now, but more sustainability issues may arise in the future, which need to be dealt with separately. This can be considered a research limitation. However, this also offers different avenues for future researchers to focus on other industries and resource limitations.

Further research into such intervention-based research (IBR) that considers cross-functional stakeholder alignment might reveal incremental dimensions and mechanisms that influence the competencies required from global automakers. The generative mechanisms associated with data management and analytical competencies can be fully incorporated in design by linking the purposes of data sharing to the overall reduction in lead times for multitier supply networks as shown in Figure 1. Thus, the provision process can be more flexible such as identifying alternative supply bases across tiers or building commercial relationships directly by bypassing a tier (for example, Tiers 1-3). There are also areas associated with competency enhancements such as sales and operations planning (S&OP) and material forecasting, considering estimates from customer shares of demand, and data sharing across multitier supply networks. Thus, more case studies can be conducted using an IBR and design science approach to enhance the MTSSCM framework to test diverse aspects of the business competencies examined in this study.

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Appendix A: Interview script for improving long-term capabilities at the automotive firm.

Governance:

- Can you describe the governance mechanism for supplier audits that your organization uses to ensure part shipments are aligned with commitments?
- What are the supply risk management (SRM) activities and what are the analytical capabilities to forecast these risks?

Collaboration:

- How does your firm manage supplier collaboration to enhance shared vision with business values and integrity?
- How is your firm engaging and collaborating with multitier suppliers to manage the current global semiconductor supply crisis?
- Is your firm able to provide raw materials directly to tier-1 suppliers through multitier collaboration and sources from tier-3 or 4 suppliers?

Transparency:

- How does your company gain visibility and transparency into potential supply shortages from multitier suppliers?
- Does your firm have visibility into inventory details (stock coverage in days) across multitier levels? How do you gather and maintain this information?
- Is your organization able to obtain visibility at different levels for: a) committed and uncommitted supply confirmations? As well as raw materials and finished products deliveries?
- How does your firm conduct commonality and standardization assessments across all semiconductor chip affected modules to reduce supply complexity?