Strategic Transformation Trends within Automobile Supply Chains in the Post-Pandemic Era

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ABSTRACT

This research delved into the transformation of supply chain strategies among automobile original equipment manufacturers (OEMs) in the post-pandemic era, motivated by the disruptions faced during the COVID-19 pandemic. This study employed qualitative research methods and conducted semi-structured interviews with employees from both supply chain and strategy functions in OEMs and suppliers. This study identified motivations for automobile supply chain strategy transformation, including the electrification trend, geopolitical events, and pandemic impacts, highlighting the need for agile and resilient supply chains. Driven by these factors, OEMs prioritized supply chain resilience through measures such as safety stock increases, dual-sourcing critical materials, and enhanced supplier collaboration. Organizational adaptations further bolstered these transformation initiatives, fostering flexibility and instilling a resilience-centric mindset. Furthermore, this study examined talent management issues and resistance to change as prominent obstacles in supply chain strategy transformation and offered targeted recommendations. The findings provided actionable insights into emerging post-pandemic supply chain transformation trends, serving as a valuable resource for automotive OEMs, suppliers, policymakers, and scholars in shaping future strategies for automobile supply chains.

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1. INTRODUCTION

1.1 Background

The COVID-19 pandemic profoundly altered the global supply chain landscape, with the automotive industry serving as a prime example of these challenges and transformations. The disruptions caused by the pandemic emphasized the critical need to reevaluate and redefine supply chain strategies, particularly in sectors like automotive where interdependencies across manufacturing, logistics, and raw materials procurement are intricate and extensive.

During the peak of the pandemic, automotive manufacturers and suppliers were confronted with unprecedented hurdles, including production halts, inventory shortages, logistical complexities, workforce constraints, and financial pressures. These challenges not only disrupted the flow of supply chains and productions but also underscored the urgent requirement for agile, resilient, and adaptable supply chain strategies to navigate future uncertainties and mitigate risks effectively.

The urgency and significance of supply chain strategy transformation have prompted major players in the automotive industry to announce transformation plans aimed at overhauling their supply chain operations comprehensively. These strategic initiatives encompass a broad spectrum of approaches, ranging from embracing digitalization and inventory management initiatives to diversifying supply chains and fostering collaborative partnerships with suppliers and ecosystem stakeholders. The overarching goal is to cultivate more robust, flexible, and responsive supply chains capable of dealing with disruptions, ensuring seamless production continuity, meeting evolving customer demands, and fostering long-term resilience.

This research delves deeply into the imperative of automobile supply chain strategy transformation in the post-pandemic era. It aims to unravel the underlying motivations driving this transformation, scrutinize the strategies adopted by industry leaders, and analyze potential challenges and opportunities associated with this transformative journey. By providing in-depth insights, references, and recommendations, this research seeks to empower key stakeholders, including OEMs and other entities across the automotive sector, to navigate the evolving landscape effectively and position themselves for sustained success in a post-pandemic world.

1.2 Research Objectives and Values

The overarching goal of this research is to delve into the transformation of supply chain strategies among automobile OEMs in the post-pandemic era. Specifically, it aims to identify the key drivers and motivations that have propelled OEMs to undertake supply chain strategy transformations in the aftermath of the pandemic. Moreover, the study seeks to examine the strategic initiatives and organizational changes implemented by OEMs to enhance supply chain resilience and adaptability in response to the challenges posed by the pandemic disruptions.

Additionally, it investigated the cultural shifts and mindset changes within OEMs that either facilitated or hindered the transformation process. The research also analyzed the evolving relationships and collaborative approaches between OEMs and their suppliers, particularly in the context of securing critical resources and components for electric vehicle production. Furthermore, it explored the role of digital technologies and their integration in supporting the transformation of automotive supply chain operations.

This research offers significant value to various stakeholders in the automotive industry and beyond. For automobile OEMs, the findings provide a comprehensive understanding of the trends shaping supply chain transformations, enabling them to craft more resilient and future-ready roadmaps. Additionally, it offers guidance on navigating anticipated challenges, such as talent shortages, cultural resistance, and the transition to a resilience-oriented mindset. For suppliers and logistics providers, the insights into localization trends, emerging supplier clusters, and heightened resilience demands can help these stakeholders recalibrate their strategies and adapt to the evolving landscape. Furthermore, the research highlights opportunities for startups and technology providers to collaborate and form strategic partnerships with industry leaders, leveraging resources through innovative solutions. Notably, by shedding light on industry dynamics and challenges, this study serves as a valuable reference for policymakers and governments to formulate policies that stimulate growth and support the automotive sector more effectively. Moreover, the comprehensive analysis of supply chain strategy trends and the exploration of strategy transformation in automotive supply chains contribute to the body of knowledge, paving the way for future research directions within academic and research communities.

2. LITERATURE REVIEW

2.1 Operation Management and Supply Chain Management Concept

The origins of operations management can be traced back to the industrial revolution, where organizations faced pressing needs to efficiently organize and manage production processes. Taylor (1911) introduced the theory of scientific management, emphasizing workflow optimization and heightened production efficiency through scientific methodologies and precise measurement (Wolniak, 2020). As industrialization and technological progress advanced, operations management evolved into an independent discipline, significantly impacting various research fields and industries. This discipline focuses on enhancing organizational capabilities and efficiency across the entire value chain, from raw material procurement to final product delivery and service provision. Key areas include resource utilization (Kosolapova et al, 2021; Ananth and Varadaraj, 2019), production efficiency improvement (Trojanowska et al, 2018; Kovács, 2018), quality control (Mitra, 2016), and supply chain coordination (Kouvelis et al, 2006; Russell and Taylor, 2011).

The development of operations management led to multiple research directions and fields, including supply chain management, quality management, inventory management, production planning and control, and project management (Sprague, 2007). Supply chain management, in particular, emerged from the continuous exploration and expansion of areas like inventory management (Wild, 2017; Toomey, 2000) and logistics management (Southern, 2011) within operations management (Lummus and Vokurka, 1999). Since the late 19th century, supply chain management has been a prominent topic in enterprise management theories, covering areas such as inventory management (Singh and Verma, 2018; Giannoccaro and Pontrandolfo, 2002; Cachon, 1999), logistics system planning (Ghiani et al, 2004; Ramos et al, 2014; Gunasekaran et al, 2007), information sharing (Cachon and Fisher, 2000; Zhou and Benton, 2007; Lee and Whang, 2000), and strategic management (Ketchen and Giunipero, 2004; Hitt, 2011).

Numerous studies have made significant contributions to inventory management theory by addressing crucial aspects such as inventory control models, strategies for cost and service level optimization, and real-time information integration. The evolution of inventory management models has been driven by diverse challenges encountered in business operations. For instance, You and Grossmann (2008) developed a comprehensive supply chain inventory model that considers both storage and transportation challenges. In a similar vein, Dejonckheere et al (2003) focused on minimizing inventory costs through the implementation of a computerized management system. Researchers have also advanced inventory management by incorporating dynamic demand considerations and integrating real-time information into inventory systems (Lee et al, 2009; Bakker et al, 2012; Teunter et al, 2010). At the same time, research on order points and quantities has emerged alongside inventory management studies (Axsäter, 2003), with data analysis technologies like quantitative algorithm optimization being integrated into inventory management research. For example, Hnaien et al (2010) developed a fuzzy inventory management model, while Altiok and Shiue (1995) contributed a multi-product inventory model based on Markov decision processes. Recent innovations include the deep reinforcement learning-driven framework introduced by Dehaybe et al (2024), showcasing advancements in inventory optimization methods.

Another significant area of research within supply chain management is logistics system planning, which involves the design and optimization of the overall logistics network to achieve efficient and cost-effective transportation and storage solutions (Winkelhaus and Grosse, 2020). Research in this field encompasses facility layout planning, transportation network optimization, and distribution route planning. For instance, Daskin (2005) studied the role of facility location selection in supply chain network design, while Mahmoodi (2019) proposed a comprehensive supply chain design model considering inventory and transportation challenges. Moreover, research on logistics network optimization has made substantial progress using exact and heuristic algorithms. For example, Cordeau et al (1998) developed an algorithm to solve real-scale logistics and transportation network design problems, and Severino et al (2021) proposed a hybrid heuristic approach using genetic algorithms and simulated annealing algorithms for inventory allocation and route optimization problems.

Additionally, emerging logistics network planning models consider more complex factors such as uncertain customer demand, inventory and transportation constraints, and vehicle and freight station resources (Rahmaniani et al, 2017; Rad et al, 2018; Daghigh et al, 2017). Transportation mode selection and route planning remain key areas of focus, as seen in studies by Baykasoğlu (2019) and Corman et al (2016), which address fleet combination optimization problems and design transportation route decision systems for large-scale warehouses with automated guided vehicles. These research endeavors align with both the practical needs of supply chain management and the ongoing development of optimization algorithms.

The focus on information sharing and coordination in supply chain management revolves around enhancing connectivity and collaboration among partners using information technology, thereby improving operational efficiency (Cachon, 2003; Kanda & Deshmukh, 2008). For instance, Sahin and Robinson (2005) delved into how information sharing impacts supply chain coordination in make-to-order production, while Özer et al (2014) examined the interplay between information sharing and trust relationships within supply chains. Datta and Christopher (2011) developed information sharing strategies and coordination mechanisms while considering supplier capacity constraints.

Moreover, trust and risk are significant themes in the study of supply chain coordination and cooperation. Kwon and Suh (2004) analyzed how trust influences cooperative relationships in supply chains amid shared incomplete information, while Govindan et al (2016) explored how trust-based collaborative business models mitigate risk propagation in supply chain networks. Agrell et al (2004) proposed risk management contracts to foster information integration in supply chains. These studies underscore the enduring concerns around trust, risk management, and information sharing in supply chain management. While these insights offer valuable guidance from various perspectives, they do not offer a universal model for supply chain management due to the dynamic challenges organizations face in practice (Fawcett and Rutner, 2014).

2.2 Supply Chain Management Empirical Studies

During the early 20th century, operations management primarily concentrated on internal production processes and enterprise management, emphasizing efficiency improvements and cost optimization (Croom et al, 2000). As markets globalized and supply chains internationalized, scholars recognized that single-enterprise management couldn't fully meet complex market demands, leading to the emergence of supply chain management concepts (Overby and Min, 2001; Giovannetti et al, 2015). From the 1980s to the 1990s, as manufacturing industries matured, logistics and inventory management within supply chains gained attention. Research focused on optimizing logistics and inventory to enhance overall supply chain efficiency (Bowersox and Closs, 1996; Larson, 2001).

Noteworthy advancements emerged, such as Toyota's JIT (Just-In-Time) process, emphasizing pull-based production to achieve zero inventory goals, widely adopted and refined (Monden, 2011). The ABC classification method, categorizing items into A, B, and C classes based on importance and applying different inventory control strategies for each class (Flores et al, 1992), became widely utilized in operational decisions like warehouse management, distribution, production planning, quality management, and resource allocation.

As global supply chains integrated, research shifted towards collaboration and integration across supply chain links. This included supply chain partnerships (Maloni and Benton, 1997; Lambert et al, 1996), optimizing information flow (Kelle and Akbulut, 2005), and supply chain risk management (Tang, 2006; Finch, 2004; Thun and Hoenig, 2011; Tummala and Schoenherr, 2011) becoming focal points. For instance, Mandal (2012) explored global supply chain resilience, while Chopra and Meindl (2001) studied information technology's impact on supply chains, deepening discussions on risk, trust, and the role of technology.

Recent years have seen supply chain management enter a digital and intelligent era. Academic research now harnesses technologies like the Internet of Things (Ben-Daya et al, 2019; Manavalan and Jayakrishna, 2019), big data (Wang et al, 2016; Gunasekaran, 2017), and artificial intelligence (Min, 2010; Baryannis et al, 2019) for digital supply chain transformations and addressing new challenges. Technologies such as RFID, GPS, and sensors (Sarac et al, 2010; He and Turner, 2021) are commonplace in warehouse and logistics management. Advanced predictive methods and optimization algorithms for supply chain decision-making, including demand forecasting models and machine learning for route optimization, alongside cloud-based intelligent supply chains (Wu et al, 2013), are rapidly evolving. Cutting-edge technologies like blockchain find application in areas such as demand forecasting and supply chain finance (Carbonneau et al, 2008; Soni et al, 2022), empowering supply chain collaboration and risk management. These research outcomes enhance supply chain efficiency but also confront operational risks, cost control challenges, ethical considerations, and other aspects (Chen et al, 2013; Boon-itt, 2009; Beamon, 2005; Simangunsong et al, 2016)

2.3 Supply Chain Management in Automobile Industry

The complexity of the automobile supply chain is rooted in its intricate layers and the extensive network of suppliers operating across multiple countries and regions (Serdarasan, 2013). This industry encompasses numerous tiers of suppliers, from raw material providers to component manufacturers and assembly plants, each playing a crucial role in the production process (Milovanović et al, 2017). While these layers add depth to the supply chain, they also introduce challenges in coordination, communication, and risk management (Huang et al, 2020). A significant contributor to this complexity is the global nature of the automotive industry (Roh et al, 2014), where suppliers and manufacturing facilities are often dispersed across different countries due to factors like cost advantages, expertise, and market proximity. Consequently, automotive companies must navigate international trade regulations (Veloso, 2002), currency fluctuations (Davarzani et al, 2015), transportation logistics (Fartaj et al, 2020), and cultural differences (Zhu et al, 2008), all of which impact supply chain operations.

Moreover, the diversity among suppliers within the automotive supply chain adds another layer of complexity, particularly in the era of electrification. Suppliers vary in size, capabilities, technological expertise, and production capacity (Veloso and Kumar, 2002). Effectively managing relationships with such a diverse supplier base necessitates robust supplier management strategies, quality control measures, and contingency plans to mitigate disruptions (Aláez-Aller and Carlos, 2010; Grötsch, 2013; Stonebraker and Afifi, 2004). This complexity is further compounded by industrial standards, regulatory compliance requirements, and evolving technologies.

Even before the pandemic, the automobile supply chain faced numerous challenges (Fan and Stevenson, 2018). Supplier dependency emerged as a critical issue, as the reliance on a network of diverse suppliers for components, materials, and technologies made automobile supply chains susceptible to disruptions in the supply of critical parts (Kim and Henderson, 2015). Hendricks and Singhal (2005) explored how supply chain glitches, including supplier dependencies, affect operational performance, while Krause et al (2007) emphasized the role of supplier development and commitment in enhancing supply chain performance. Insights from Sheffi (2005) on building resilient supply chains are particularly relevant for managing supplier dependencies effectively. Additionally, logistics challenges significantly impact supply chain efficiency and effectiveness. Christopher's research (2016) highlighted the complexities of coordinating suppliers across multiple regions and countries, addressing issues such as cultural differences, varying regulations, and logistical coordination challenges. Jain and Benyoucef (2008) delve into the intricacies of managing transportation networks, including route optimization, mode selection, and transportation cost management, with the reliance on multiple transport modes adding layers of complexity to transportation logistics.

2.4 Implications of Pandemic on Automobile Supply Chain Management

The challenges faced by automobile supply chains increased dramatically during the pandemic, prompting extensive research to explore the underlying reasons and potential solutions for the supply chain crisis.

nderstanding the root causes of the supply chain crisis during the pandemic is crucial for devising effective solutions. Demand volatility and uncertainty were major contributing factors, as highlighted by Gerchak and Wang (2020) and Bhatt et al (2020), who pointed out abrupt shifts in consumer demand patterns due to lockdowns and economic uncertainties. These shifts led to challenges in production planning and inventory management. Simultaneously, supply chain disruptions, caused by lockdowns, travel restrictions, and factory closures, significantly impacted the availability of raw materials and components and exacerbating production delays and inventory shortages (Ivanov and Dolgui, 2020). Logistics challenges, including transportation bottlenecks and network disruptions, further strained supply chain resilience and operational continuity (Singh et al, 2021). Workforce-related issues such as labor shortages and absenteeism added complexity to manufacturing processes and contributed to supply chain disruptions (Ambrogio et al, 2022). Financial strain and cash flow problems created additional hurdles, impacting liquidity and financial stability across the supply chain (Kapparashetty, 2020). These studies on the reasons for the supply chain crisis provide valuable insights for developing potential solutions.

The consequences of the supply chain crisis triggered a dramatic need for supply chain strategy transformation in the automobile industry. The crisis acted as a catalyst for innovation and transformation. In reaction, automakers adopted digitalization, sustainability initiatives, and diversified supply chain strategies to create stronger and more adaptable supply chains (Iansiti and Lakhani, 2020). Studies by Ye et al (2022) and Ivanov (2021) addressed the shift towards digital supply chain transformation as a key solution.

Collaborative efforts and partnerships also emerged as crucial strategies for supply chain resilience in the automotive sector (Duong and Chong, 2020). Collaborations with suppliers, logistics providers, and ecosystem partners became instrumental in mitigating supply chain disruptions, ensuring continuity in production, and meeting changing customer demands. Research by Corbett et al (1999) and Kukkamalla et al (2021) underscored the importance of supply chain collaboration and partnerships in overcoming crisis challenges, proposing collaborative planning, forecasting, and replenishment initiatives, supplier collaboration platforms, and ecosystem partnerships as effective strategies for enhancing supply chain resilience and responsiveness. The crisis forced automobile manufacturers to rethink their supply chain resilience, localization strategies, and risk management practices (Craighead et al, 2020; Sheffi, 2020), highlighting the need for agile and resilient supply chain strategies to navigate disruptions effectively (Saarinen et al, 2020; Konstantinou et al, 2021).

In summary, these studies provide invaluable insights into the reasons for supply chain disruptions and highlight the strategies adopted by automakers to navigate challenges, emphasizing the importance of resilience, agility, collaboration, and technological transformation in ensuring supply chain continuity in the post-pandemic era. They also underscore the necessity of supply chain strategy transformation in the automobile industry.

3. METHODOLOGY

3.1 Research Design

3.1.1 Research Process

This study adopted a qualitative multiple case studies research approach, utilizing interviews and literature review as primary methods. Multiple case studies were chosen over single case studies due to their suitability in understanding differences and similarities, aligning with the research's objective to identify trends in an industry. The research process was divided into two phases: the desk research phase and the interview phase.

During the desk research phase, the focus was on reviewing academic studies and industrial reports related to the research topic. This phase aimed to analyze historical trends in supply chain strategy evolution and transformation within the automotive sector. Literature related to operations management, supply chain management, and organizational behavior was systematically reviewed to explain potential findings. Additionally, reviews of industrial reports since the pandemic were conducted to capture the most current studies in this area.

In the interview phase, the emphasis was on exploring motivations, initiatives, trends, and outcomes of post-pandemic strategic transformations in automotive supply chains. Interviews were conducted with managers from the strategic management and supply chain management departments of representative companies in the automotive industry. The results of these interviews were summarized and analyzed to identify trends in strategic transformation and potential challenges.

3.1.2 Research Scope

This research focused mainly on multinational OEMs and tier-1 suppliers in the context of supply chain strategy transformation in the post-pandemic era. Recognizing the growing importance of EVs and the pivotal role of battery technology in shaping the future of the automotive industry, this research strategically selected EV OEMs and battery suppliers as key stakeholders for analysis.

OEMs play a pivotal role in the automotive industry as they are responsible for designing, manufacturing, and distributing vehicles to end customers. OEMs are considered to be the core of automobile supply chains as their strategic decisions and actions have a significant impact on the entire supply chain ecosystem. This fact makes OEMs a crucial focal point for studying supply chain transformations. At the same time, tier-1 suppliers are critical partners to OEMs, providing essential components, parts, and systems that are integral to vehicle production. The relationship between OEMs and tier-1 suppliers is highly interdependent, with collaborative efforts and strategic alignments shaping the efficiency and effectiveness of the supply chain. Moreover, by including tier-1 suppliers in the research scope, a holistic understanding of supply chain dynamics, challenges, and transformation initiatives can be gained.

Furthermore, the post-pandemic era has introduced unprecedented disruptions and challenges to supply chains in the automotive sector and OEMs and tier-1 suppliers have been at the forefront of navigating these challenges. Studying the experiences and strategies of multinational OEMs and tier 1 suppliers provides valuable insights into effective approaches for adapting and transforming supply chains in response to dynamic external environments.

Focusing on these multinational OEMs and tier-1 suppliers allows for a targeted examination of key stakeholders who are central to supply chain strategy transformation efforts. Their experiences, challenges, and strategic initiatives serve as valuable case studies and benchmarks for understanding broader industry trends and best practices in supply chain management post-pandemic.

3.2 Data Collection

During the data collection phase, 15 interviews were conducted with employees from 6 OEMs and 3 suppliers, strategically selected to represent diverse segments within the automotive industry. The companies interviewed included those producing economy cars, focusing on the luxury market, exclusively manufacturing EVs, and having comprehensive portfolios. Tier-1 suppliers of critical components such as chips, engines, and batteries were chosen due to their significant role during the pandemic and their longstanding business relationships with the selected OEMs. All companies selected are industrial leaders with relatively stable operations during the pandemic years, minimizing the influence of unrelated factors on the research.

Interviewees from both supply chain functions and strategy functions were selected, recognizing that supply chain strategy transformation required joint efforts across multiple departments. The functions and companies of interviewees involved in this research are summarized in Table 1.

Table 1. Interviewee information.

Company	Supply Chain	Strategy
Mercedes-Benz	Yes	Yes
BMW	Yes	Yes
Ford Motor	Yes	No
Tesla	Yes	No
BYD	Yes	Yes
Nissan Motor	Yes	Yes
Bosch	Yes	No
ZF	Yes	Yes
CATL	Yes	No

Interviews were conducted in a semi-structured manner to capture essential information while allowing flexibility in interviewee responses (Barriball and White, 1994). The first phase of interviews targeted OEMs, guided by an interview questionnaire developed after desk research (see Appendix 1). This questionnaire covered topics such as motivation, timing, roadmap, methods, and challenges of supply chain strategy transformation. Data collected from these interviews were summarized to identify trends. Subsequently, interview questionnaires for suppliers were tailored based on insights gained from OEM interviews. The main goal of the second round of interviews with suppliers was to understand the implications of OEMs' supply chain transformation on suppliers, including insights into partnerships and power dynamics.

All interviews were conducted online due to logistical challenges posed by the geographic dispersion of researchers and interviewees. To minimize bias, interviews began with a consistent statement of research purpose, and key questions were asked in a standardized context and order. Over-guiding was avoided, and ambiguous responses were clarified during or after interviews. Both interviewers and interviewees reviewed notes to ensure accuracy and understanding.

3.3 Data Analytics

Data analytics in this research followed a structured sequence of collecting data, identifying similarities, and uncovering relationships. After the interviews, notes were coded and organized into a summary table. Each sentence was abstracted by removing irrelevant and repeated words, and labels or short texts were used to highlight core ideas regarding supply chain strategy changes. These core ideas were then categorized into different themes based on similarity, forming the basis for thematic findings and supporting evidence.

Following theme identification, the data was reviewed to uncover relationships at the core idea level. A matrix was constructed to display relationships between different core ideas, with a numerical scale from 1 to 5 indicating connection strength. Strong connections were prioritized to explain relationships among different phenomena, contributing to the development of key findings based on trends and their interrelationships. This approach ensured a systematic analysis that integrated both key trends and the underlying relationships among them.

4. FINDINGS

4.1 Supply Chain Strategy Transformation is Driven Primarily by External Factors

The motivation for supply chain strategy transformation in the automobile industry during the post-pandemic era distinguishes this wave of transformation from previous instances, as revealed by the interview results. Unlike earlier transformations driven primarily by economic factors or technological advancements, the current shift in supply chain strategy is predominantly catalyzed by unexpected crises, alongside industrial shifts like the electrification trend and geopolitical events such as the Ukraine-Russia War. The interplay of these factors makes the effects on supply chain strategies complex, necessitating a comprehensive understanding of the motivations driving the transformation. Such understanding is crucial for seizing the opportunities arising from these changes. This paper provides a summary of the diverse external and internal motivations and draws conclusions based on their inherent nature.

4.1.1 Industrial Factors Brings both Challenges and Opportunities

One of the most influential industrial trends is electrification, driven by environmental concerns and regulatory policies, leading to a significant transformation in the automotive industry. Nearly all major automobile OEMs have strategically aligned their business plans with this trend, investing heavily in electric vehicle development and production. The implications of the electrification tide extend from product to upgrading production processes and also bring changes to supply chain fields. As EVs have a distinct power system compared to fuel cars, different components are used to build EVs, necessitating adjustments in collaboration with relatively new and less experienced EV component suppliers. Additionally, the electrification trend motivates companies to build strong partnerships or invest in suppliers to secure stable supplies at favorable prices in the long term.

The implications of electrification can be summarized in two perspectives. Firstly, all major players in the automobile industry have announced strategies to transition their portfolios into electric vehicles. Most companies begin by converting popular models from fuel versions to electric or hybrid versions, leveraging their strong brand names and customer loyalty. This results in a more complex portfolio and production needs, leading to higher requirements for supply chain efficiency from more complex supply chain networks and motivating auto companies to upgrade their supply chain strategies.

Secondly, new players have entered the automobile industry, such as Tesla, Rivian, Lucid Motors, and Xpeng Motors, which build models from scratch with a focus on making vehicles smarter. They lead trends in smart cockpit design, autonomous driving, and smart entertainment functions, which have become available in most brands due to emerging customer needs. This trend also creates demands for new suppliers, both hardware and software, and necessitates closer collaboration among software suppliers, hardware suppliers, and automobile OEMs, facilitating supply chain strategy upgrades. Notably, due to the high sunk costs in the automobile business, these emerging players primarily target or begin by targeting the high-end market, exerting more pressure on luxury auto companies.

One significant finding from the research is the diversity of opinions among companies regarding the electrification trend. While there is a shared understanding that it drives supply chain strategy transformation, differing arguments exist regarding its motivating factors. The research results highlight that luxury brands tend to view electrification more as a challenge, whereas other large enterprises see it as an opportunity. These differing perspectives can be attributed to market dynamics and supply competitions. From a market standpoint, luxury brands face challenges as emerging brands erode their market share, while the emergence of smart vehicles prompts customers to question the value of luxury brand car models. Additionally, luxury brands typically have smaller order volumes with key electric component suppliers, making it harder to secure prioritization. This dual pressure from demand and supply size leads luxury automobile OEMs to focus more on the negative impacts of the electrification trend, constraining their strategy design and resulting in a more passive transformation of their supply chain strategy.

> *"The electrification was a big thing... Customers are provided with more options, and some are really good options. People who buy luxury cars are the ones willing to try new things. That's a big challenge for us, and our supply chain system needs to respond to this challenge." (Logistics Supplier Manager, Luxury OEM)*

Conversely, for non-luxury large enterprises in the industry, electrification is perceived as less threatening. Their diverse customer base and larger order volumes provide stability, allowing them to secure priorities from key suppliers more effectively. This affords these companies the luxury of designing their supply chain strategy transformation proactively. As a result, the electrification trend is seen as a mature input in their strategy design, facilitating a more active and strategic approach to supply chain transformation.

4.1.2 Political Factors Increases Uncertainty of External Environment

As the automobile industry continues to evolve, supplier clusters have emerged in various global locations. The supply chain for automobile components is highly intricate, involving multiple layers and suppliers from different countries and regions for technological or economic reasons. No automobile can be manufactured using solely local materials, making political factors crucial in shaping OEMs' supply chains. Even though OEMs prefer suppliers in stable political environments, political dynamics are inherently dynamic, and stability cannot always be guaranteed. Additionally, given the high volume of orders from OEMs, they must prioritize the most economical sourcing options and often cannot prioritize political factors in their sourcing criteria.

The frequent and unexpected political changes during the pandemic have caused significant disruptions to automobile supply chains, some of which cannot be rectified in the short term, while others have created temporary benefits. Major political factors, such as the enactment of automobile-related regulations and declarations of wars in certain countries or regions, have facilitated supply chain strategy transformations.

Ukraine-Russia War

The Ukraine-Russia War has had profound implications for the automobile industry beyond losing the Russian market and escalating oil and metal material prices. Firstly, OEMs have had to find new suppliers to replace tier-1 suppliers located in Ukraine or Russia. The wiring harness category has been particularly affected, with many European OEMs reliant on Ukrainian suppliers. Due to inconsistent production in Ukraine during the war, many manufacturers relocated production to other countries, resulting in extended ramp-up times and sharp price increases due to elevated land and labor costs. OEMs have had to seek new wire harness suppliers in locations such as Mexico or China.

Additionally, apart from tier-1 suppliers in war-affected regions, the conflict has indirectly impacted chip materials supply. Helium and palladium, crucial raw materials for chip manufacturing, are major exports from Ukraine and Russia, posing a serious threat to their stable supply. Although semiconductor companies initially increased stock levels at the war's onset, ongoing concerns persist as the conflict continues. Many companies are investing in alternatives to helium, but this transition takes time and requires substantial investment.

The war led to the cessation of operations at ports along the Black Sea, causing congestion in other European harbors. Additionally, approximately 15% of maritime workers come from these two countries (Internation Chamber of Shipping, 2022), leading to labor shortages in the maritime industry, which is a primary transportation option for most automobile OEMs. These congestion and labor issues have significantly extended lead times for material deliveries, consequently increasing pipeline stock in supply chains. Furthermore, the conflict blocked Europe-Asia truck and train transportation routes that previously traversed Russia. As a result, goods that were typically transported by trucks and trains now have to use air cargo, which is significantly more expensive and has limited capacities. Compounding this issue, cargo planes must bypass other European areas due to restrictions on entering the war zone, further driving up cargo prices.

In summary, the war has caused direct and indirect material shortages and disrupted all European-Asia transportation modes, resulting in higher transportation costs and increased supply chain pipeline stock for automobile supply chains. OEMs have had to adapt their supply chain strategies by sourcing new vendors in alternative regions, implementing precise inventory management methods, and adopting more flexible production modes.

China Joint-Venture Restriction Termination

China has long been a key player in the global automobile market and supply chain. In an effort to protect local automobile OEMs, the Chinese government implemented stringent policies requiring foreign OEMs to establish joint ventures (JVs) when setting up production sites in China. The JV business model posed challenges for supply chains, particularly in terms of sourcing criteria, responsibility alignment, and localization rates. In 2018, China lifted the JV restriction for electric vehicles (EVs) and special-purpose vehicles, followed by a complete termination of the JV restriction for all vehicle types in 2022.

This change has opened up broader market opportunities for international OEMs and suppliers, fostering technological innovation and collaboration. OEMs now have greater flexibility in selecting suppliers, accessing more competitive components and services, and optimizing supply chain costs and efficiency. Importantly, the termination of the JV restriction has significantly accelerated the development of EV OEMs and suppliers. Immediately following the policy change in the EV industry in 2018, Tesla initiated the construction of its Gigafactory in Shanghai and commenced mass production within a year. The significant volume of Tesla's operations has spurred the growth of EV component suppliers in China, making it a major cluster for EV component suppliers and creating a thriving environment for other Asian EV OEMs.

Trade Disputes between China and the United States

Approximately 25% of Chinese auto parts exports are destined for the United States, with annual imports of automobile parts from China totaling around $10 billion, second only to Mexico U.S. (International Trade Commission, 2019). Given this substantial transaction volume, the implications of trade disputes between China and the US on the automobile industry are significant.

The high tariff barriers resulting from these trade disputes have compelled OEMs to reconfigure their supply chains, sourcing materials from alternative countries and regions, thereby increasing the complexity of their supply chain networks. This often involves managing more suppliers and third-party logistics service providers. The impact of high tariffs on certain materials has forced OEMs to break them down into sub-level materials due to affordability concerns, posing challenges in procurement management. Some OEMs and tier-1 suppliers have responded to these challenges by relocating their production bases to other regions such as Southeast Asia and India to enhance supply chain resilience, although this shift may introduce new risks. Uncertainties surrounding factors like investment environments, employee skills, and supplier densities further contribute to the complexity.

The primary concern for OEMs is the uncertainty and unpredictability of the duration of these trade disputes, prompting them to adapt their supply chain strategies based on worst-case scenarios and navigate the increased tariff barriers and geographical complexities involved in diversifying their supply chain footprint.

4.1.3 Unexpected Crisis Challenged Supply Chain Resilience

The pandemic has had a profound impact on the automotive industry's supply chain strategies, particularly in terms of supply disruptions, which have been the most significant challenge. The chip shortage, a longstanding concern in the automobile industry, reached its peak during the pandemic. OEMs faced production line shutdowns due to chip shortages, attributed to raw material scarcity, labor shortages at multiple tier suppliers, and transportation disruptions from border closures. These challenges underscored the importance of vendor relationship management and risk mitigation strategies.

> *“I knew my clients are waiting for this part to kick off production but half of my employees are quarantined.” (Fulfillment Manager, Tier-1 Supplier)*

Demand fluctuations and production disruptions also emerged prominently during the pandemic. Fluctuations in consumer demand posed challenges to production schedules, resulting in delays and disruptions in material stock consumption. This situation contributed to unusually high material stock levels, where critical materials faced shortages while warehouses were overflowing with non-critical materials. OEMs had to secure external storage space and engage temporary logistics service providers to manage the excess stock, leading to financial strains and challenges in inventory management systems. To address these issues, OEMs enhanced inventory management practices, optimized stock levels, and expanded warehouse capacity.

> *"The key problem (during the pandemic) was that everything was always changing. It was a torture for us... I had 3 months' worth of A-pillar covers but no sound control units in my warehouse." (Inventory Manager, OEM)*

Furthermore, the pandemic led to increased prices across all material categories, as well as logistics services and labor. Rising material costs intensified pressure on OEMs to enhance supply chain efficiency. This imperative drove efforts towards supply chain digitization and resilience-building. OEMs accelerated the digitization of supply chains, leveraging digital tools for real-time visibility, predictive analytics, and agile decision-making. Resilience-building initiatives focused on creating flexible supply chains capable of responding swiftly to dynamic market conditions.

Moreover, unforeseen events such as the Suez Canal blockade and the fire at the main factory of Japanese semiconductor giant Renesas Electronics Corporation exacerbated challenges in the supply chain. These crises compelled OEMs to establish emergency task forces to secure critical parts, accelerate digital transformations to reduce reliance on manual labor, and enhance communication efficiency and transparency. For many OEMs, the pandemic served as a pivotal moment that catalyzed a shift in the mindset of supply chain management.

> *"I think the biggest change brought by the pandemic is a shift in mindset. We have become more open to technology and are more willing to invest in research to improve efficiency." (Supply Chain General Manager, OEM)*

4.2 General Transformation Trend

4.2.1 Resilience Emerges as the New Key Focus

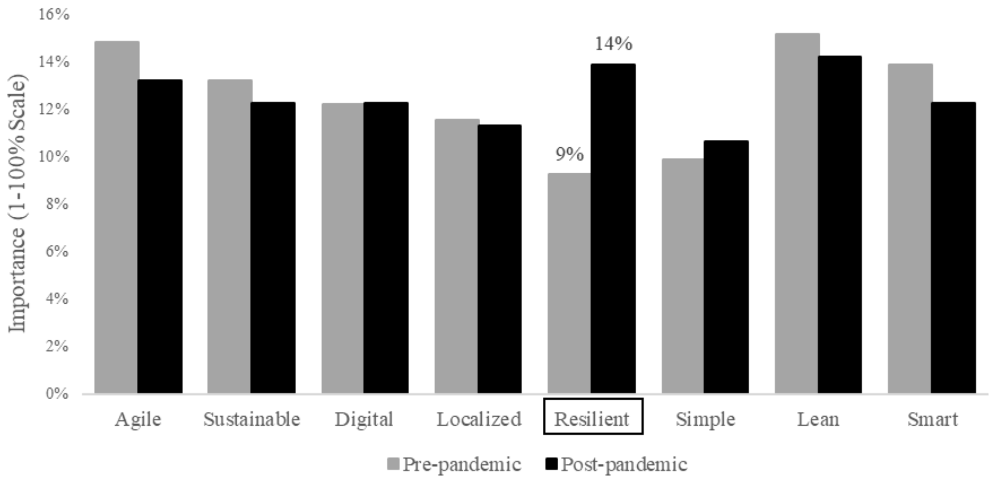

Figure 1. Change in supply chain principles priorities

The importance of supply chain principles has evolved significantly, as depicted in Figure 1 based on interview results. The top three principles have transitioned from lean, agile, and smart to lean, resilient, and agile. Notably, there has been a substantial increase in the emphasis on resilience. Previously, OEM supply chains primarily aimed to save costs, but during the pandemic, the priority shifted to maintaining operations, highlighting the criticality of supply chain resilience. Additionally, simplicity has gained prominence as EV models diversify OEM portfolios, leading to strategies such as parts localization, consolidation center establishment, and increased component sharing among models to streamline supply chains. Digitalization has also become more important post-pandemic, enhancing data exchange efficiency and supply chain visibility.

Resilience is defined differently by various companies but generally entails the ability to anticipate, adapt to, and recover from disruptions, challenges, or changes in the operating environment. A resilient supply chain can withstand disruptions, ensuring operational continuity and minimizing adverse impacts on customers, stakeholders, and overall business operations. A key trend in building resilient supply chains is the evolution of inventory management principles. Typically driven by Just-In-Time (JIT) strategies, automobile supply chains also incorporate a level of safety stock known as Just-In-Case (JIC) stock, which proved invaluable during the pandemic for reacting to supply crises. OEMs are adjusting their inventory management strategies, with JIC stock gaining increasing importance.

Supply chain resilience extends beyond inventory management, influencing systematic updates to management methods, including areas such as finance, process upgrades, and talent management.

> *"To me resilience is about how you react to chaos, how you organize people, how you make budget for nature disasters… (in a resilient supply chain) we have a list of all the situations that might happen and solutions to support every key point in the supply chain under each scenario. We also have qualified people to monitor this process." (Supply Chain Vice President, OEM)*

By prioritizing resilience in supply chain strategy transformation, OEMs aim to enhance risk management, visibility, transparency, and collaboration with suppliers through supply chain initiatives. To build resilient supply chains, OEMs proactively identify potential risks and vulnerabilities, such as natural disasters, geopolitical events, supplier disruptions, or demand fluctuations. Efforts are directed towards reducing disruption impacts through risk mitigation strategies, contingency plans, and dual sourcing options as integral parts of supply chain strategy transformation.

Furthermore, resilient supply chains exhibit real-time visibility and transparency across the entire supply network. This visibility enables effective tracking of inventory, production status, supplier performance, and potential disruptions, facilitating proactive decision-making and risk management. Strong collaboration and relationships with suppliers, partners, and stakeholders are fostered, encompassing effective communication, trust-building, information sharing, and joint efforts on risk mitigation strategies, contingency planning, and continuous improvement initiatives.

It's worth noting that building resilient supply chains is an ongoing improvement process expected to continue in the near future. OEMs are investing in technologies to reduce dependence on logistics labor and enhance relationships with suppliers, along with mapping supply chain networks to bolster visibility.

4.2.2 Simplification in Supply Chain and Research & Development Became a Trend

As EVs have fundamentally different power systems compared to traditional fuel-powered cars, OEMs are struggling with the challenge of managing an increasingly complex array of part numbers and suppliers. To address these difficulties, many OEMs are actively working to streamline and simplify their supply chains, with initiatives stemming from both the supply R&D perspectives.

On the supply chain side, common initiatives include revising safety stock strategies, leveraging consolidation centers, and emphasizing the use of local suppliers. The interview results indicate that while OEMs are adopting flexible production models where both EVs and conventional vehicles share production lines and facilities, there's also a trend of establishing new plants dedicated solely to EV production. Traditionally, each plant would maintain separate safety stocks. However, during the pandemic-induced supply crises, companies resorted to reallocating stock across plants, proving to be a viable solution to enhance supply chain agility and reduce stock levels. Companies define the geographic scope of factories sharing safety stock and cross-deliver stock as needed to demanding production sites. This strategy also aids in minimizing scrap costs at the end of production. The implementation and impact of this strategy vary among OEMs, typically starting with non-critical materials, especially those common to both EVs and conventional vehicles, such as screws and fasteners.

Another significant initiative from the supply chain perspective is sourcing from local suppliers. Localizing sourcing can provide substantial benefits in terms of simplifying supply chains. By selecting local suppliers, lead times can be significantly reduced, and OEMs can maintain lower stock levels in their pipelines. This approach reduces the risk of interruptions since there are no regional borders to navigate in transportation routes. Additionally, apart from sourcing from local tier-1 suppliers, OEMs are simplifying their supply chains by implementing criteria that require a minimum proportion of local materials to be used by tier-1 suppliers and by restricting the geographic scope of sub-suppliers.

The shift in supply chain strategy has also prompted initiatives from the R&D side. One notable trend is the emphasis on developing shared components for use in both EVs and conventional vehicles, aimed at reducing the number of part numbers and suppliers. This consolidation will undoubtedly shrink the size of the supply chain network, leading to savings in supply management, quality monitoring, and relationship maintenance efforts. Additionally, reducing the number of suppliers exclusive to EV components can enhance the density of the supplier network, thereby improving transportation efficiency. Moreover, developing more common parts can create economies of scale, reducing purchase and supply chain costs. For instance, larger order sizes can increase truck utilization rates, resulting in logistics cost savings. Fewer part numbers also simplify warehouse and inventory management, leading to reduced warehousing and inventory holding costs.

Most of these initiatives require collaborative efforts across multiple functions within OEMs. The interview results indicate that OEMs are structuring internal simplification projects involving departments such as marketing, R&D, manufacturing, and supply chain. These projects are typically led by manufacturing or supply chain teams, with clearly defined responsibilities for each team based on their expertise. The collaborative effort leverages the collective knowledge of these teams, leading to positive outcomes. For example, in a project focusing on developing common parts, the R&D team proposes component changes, the marketing team evaluates customer reactions, the manufacturing team adjusts production lines, and the supply chain team redesigns line-feeding layouts and organizes material order changes to minimize scrap costs. Teams then track the implications and continuously improve processes.

However, it's essential to note that while simplification strategies are a general trend, there may be disagreements among departments, necessitating efforts to align the interests of key stakeholders and design project structures that match duties with responsibilities.

> *"Our (complexity reduction) project is led by the chief manufacturer officer. We (supply chain team) love it. The manufacturing team likes it. Production development team likes it. But marketing is not in favor of it. They don't want to change any functions on the existing models. Customers want many different functions and marketing never wants cut any single of them… but they know this (complexity reduction project) is a must to cut down cost." (Supply Chain General Manager, OEM)*

4.2.3 Electrification Brings Power Dynamic in Supplier Relationship Management

The electrification trend has led to the emergence of numerous suppliers. With battery technology as the cornerstone of EV advancements, new supplier clusters have formed around major battery suppliers in China. Simultaneously, the rising demand for EVs has amplified the need for vehicle entertainment systems, enhancing electronic component supplier clusters in America, China, and Europe. These new suppliers have brought about a shift in power dynamics within the automotive industry.

There are typically 3 types of situations in the supplier and auto maker relationship. One type is that automobile OEM take the domestic position. This is common in highly competitive market and generally for suppliers that can be replaceable easily. For example, plastics panels and wiring harnesses. The other type is that the automobile OEM and domestics share equal power in the relationship, which is common in the situation where the cost of changing supplier is very high either because the high investment in co-R&D or because the supplier takes a majority of market share. Examples for this case include metal connectors and window shield. In this case, although the cost of sourcing new suppliers is high, there is alternatives in the market. The third type is that the suppliers are at the domestic position because they are the only one in the market that have certain technologies. This situation is rare. Examples for this type of relationship include certain semiconductor components, engine components, and transmission components. Compared to fuel vehicles, a significant larger proportion of EV featured components are in the third type because of their advanced technologies. For examples, 34.8% of the batteries used on EVs come from CATL and 91.8% of demand are supplies by 10 vendors. Most of companies need to rely on sole supplier for battery supply. This situation positioned challenges in the supplier management and sourcing strategies for automobile OEM.

Apart from power dynamics, auto manufacturers face challenges stemming from less mature electronic component suppliers. These suppliers often struggle to guarantee high-quality supply and efficient customer service due to their limited experience. Even leading suppliers like CATL may not match the quality consistency of mature engine component suppliers. For medium and small-sized suppliers, maintaining continuous supply remains uncertain. However, the extensive experience and knowledge in production and management give automobile OEMs a unique advantage and power in negotiations.

To navigate this unique power dynamic, automakers have made strategic adjustments in their supply chain strategies to effectively manage relationships with electronic component suppliers. These adaptations encompass both inter-corporate and intra-corporate efforts. Inter-corporate strategies primarily involve investing in cultivating long-term partnerships rather than transactional interactions with suppliers. A notable trend is the leveraging of automakers' experience and expertise to facilitate the growth of suppliers and ensure a stable supply of high-quality EV components at competitive prices.

Automobile OEMs also offer guidance and support to prioritize suppliers with established mass production capabilities. Additionally, they invest in early-stage potential suppliers to gain access to cutting-edge technologies within the industry. These initiatives, which will be further elaborated in section 4.3.4, demonstrate a proactive approach by OEMs to secure reliable and innovative supply chains.

Internally, automakers have implemented intra-corporate initiatives alongside their inter-corporate transformations. While inter-corporate changes yield long-term benefits, intra-corporate actions result in more immediate adjustments. Common intra-corporate measures include increasing safety stock levels, adopting flexible transportation methods, extending demand forecasts, and implementing on-site retrofit processes.

These measures introduce flexibility to the traditional just-in-time management framework, enhancing the agility of EV component supply chains and providing OEMs with buffers against unforeseen supply disruptions. Longer demand forecasts enable EV component suppliers to better plan production schedules and proactively address potential supply issues. On-site retrofitting, typically utilized during in-house assembly processes, has been extended to EV components, where supplier engineers rectify quality issues directly on the production line. While these measures effectively mitigate supply instability, they also incur additional supply chain costs. Therefore, they are implemented as short-term solutions tailored to specific suppliers as needed.

However, managing these new dynamics alongside traditional approaches poses challenges for supply chain employees. New key performance indicators (KPIs) and temporary measures are necessary to monitor and manage EV suppliers effectively. For instance, separate reporting of delivery discrepancies for EV suppliers until they align with other suppliers' performance levels is a common practice. Additionally, tailored KPIs are developed to scrutinize details specific to these suppliers, minimizing supply interruptions.

> *"You can't imagine how many things we need to monitor from one battery supplier. They have caused all kinds of troubles. We have to monitor the delivery time, the accuracy of the delivered quantity, the package status, and even the training status of their logistics handlers… It has been quite a challenge, but now we see hope, and we are quite confident that they will catch up soon. The silver lining is that we guided them through this process, so they know how to do it our way." (Supply Manager, OEM)*

4.3 Roadmap to Supply Chain Strategy Transition

4.3.1 Multi-Level Organizational Changes Provide Preconditions

To transform their supply chain strategy, OEMs have implemented various organizational changes. This research analyzed the actions taken by the interviewed OEMs and summarized common patterns in perspectives, such as organizational structure and power dynamics behind these actions.

New Positions

One of the most common trends in organizational change is the creation of new positions and teams to support supply chain strategy transformation. These changes, initially implemented during the pandemic, were retained permanently in the post-pandemic era. Coordination positions were established to facilitate relationships between vendors and OEMs, with titles such as critical supply manager and capacity manager. These new positions combine traditional procurement functions, vendor management, inventory control, and data analytics, albeit in varying proportions across organizations. Given the high requirements for internal communication and external collaboration in these positions, most companies chose to transfer experienced employees from related teams within supply chain, manufacturing, or R&D departments to fill these roles rather than hiring externally.

However, a common concern with these positions is their source of power. Given their coordination nature, individuals in these positions require real-time information input from various departments. The accuracy of this input directly impacts their decision-making and, consequently, their work quality and supply chain performance. Additionally, these positions bear the responsibility of providing accurate output to other teams. This job nature suggests that these positions should have senior authority over the information providers, either formally or informally. In practice, the power of employees in these positions mostly comes from their knowledge, experience, or network rather than solely from their job title. This situation raises concerns about the sustainability of the power structure associated with these roles.

> *"I like this job, but sometimes I face difficulties collecting data as my colleagues have other tasks with higher priority. I cannot push them to respond to my emails promptly."(Critical Material Manager, OEM)*

Agile sourcing

Another trend in the organization changes is the raising power of procurement departments, especially in the sourcing function. Firstly, as the supply crisis, electrification, and politics Another trend in organizational changes is the increasing power of procurement departments, particularly in sourcing functions. The supply crisis, electrification, and political factors directly contributed to the growth of sourcing teams during the pandemic, as they were tasked with sourcing new suppliers to meet emerging needs for OEMs. This situation elevated the power of sourcing teams as key players in resolving supply crises for the company. Moreover, these challenges necessitated agile sourcing practices, requiring rich sourcing experience and a deep understanding of industry dynamics. Given the demand for specialized talent in agile sourcing, OEMs hired experts from their suppliers or other industries to fulfill these needs. Additionally, agile sourcing necessitated adjustments in procurement processes and frequent internal information exchange, typically led by the sourcing team, further enhancing their accountability and power.

Simultaneously, OEMs developed dual-sourcing capabilities for critical materials to enhance supply chain resilience. This strategy also increased tasks for sourcing teams and fostered dual-directional communication between sourcing and R&D teams. Traditionally, sourcing teams received information and requirements from R&D teams. However, during the pandemic, sourcing tasks were driven by supply chain issues, initiating communication from the supply chain side to the R&D team. This two-way communication not only strengthened the relationship between sourcing and R&D but also empowered the sourcing team as key information providers. These factors collectively contributed to the increased power and size of sourcing teams.

Furthermore, the structure of sourcing teams changed post-pandemic, with local sourcing teams experiencing more growth than international sourcing teams. This aligns with the localization projects aimed at reducing complexity and increasing supply chain resilience. Instead of receiving localization proposals from R&D, local sourcing teams now receive signals from supply managers and international sourcing teams regarding critical materials. This enhanced communication channel fosters agility in sourcing for critical parts. Figure 2 summarized the change in communication channels related to sourcing since pandemic. The new channels emerged are leading sourcing towards a more agile direction and are an important part of post-pandemic supply chain strategy transformation.

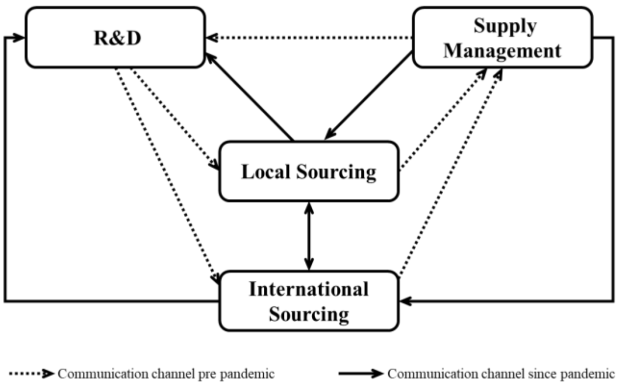

Figure 2. Sourcing related communication channel change since pandemic.

Early involvement of supply chain in product lifecycle

The supply chain crisis highlighted the critical role of stable supply chains, leading to increased attention on involving supply chain teams earlier in the production development process.

Traditionally, supply chain teams were engaged only during the tryout phase. In a typical production lifecycle, the production design phase is led by R&D and marketing teams. Sourcing and procurement functions are typically activated afterward, once the car model design is approved, and the initial sales plan is prepared. During the tryout phase, supply chain planning and operations teams step in to order materials for trial runs and design warehouse layouts, line-feeding strategies, stock control plans, and transportation methods for materials. This phase involves frequent interactions among supply chain, manufacturing, R&D, and quality departments to ensure the car model can be efficiently produced at scale. As mass production begins, R&D, supply chain planning, and sourcing teams often step back, and operations become the most active supply chain function.

However, given the significant costs associated with re-sourcing and redesigning after a supply crisis, companies are taking proactive measures to mitigate these risks by involving supply chain functions earlier in the production development process. Some OEMs now engage supply chain teams as early as the production design phase. This proactive approach helps supply chain teams prepare in advance, better identify potential risks, track risks from the early phase, and yield benefits such as identifying opportunities to build shared components among multiple car models. New indicators are incorporated early in decision-making processes, including the feasibility of dual-sourcing, the locations of tier-1 and tier-2 suppliers, the impact on supplier network density, and supplier capacity. This initiative, driven by the supply crisis during the pandemic and further developed in the post-pandemic era, highlights the necessity of building efficient supply chains for OEMs in challenging environments.

4.3.2 Planning Process Change Makes Supply Chain Voice Heard Early

An essential aspect of supply chain strategy transformation in the post-pandemic era is the evolution of the planning process. The significant change is considering material supply information as a crucial input at earlier planning stages. Additionally, there's a growing trend among OEMs to leverage marketing and sales solutions to influence customer choices, thereby alleviating delivery pressures caused by material supply constraints.

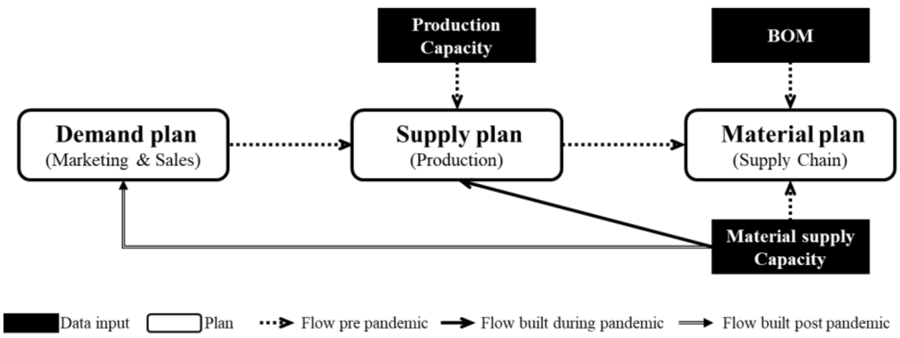

Figure 3. Planning process change since the pandemic.

Figure 3 illustrates the shifts in the planning process since the pandemic. Previously, the traditional planning process followed a sequence of demand planning, supply planning, and material planning. In this approach, marketing and sales teams gathered market information to forecast demand accurately. A demand plan based solely on customer demand was formulated, considering constraints such as production capacity across all factories. Subsequently, an optimized supply plan was devised, factoring in elements like the bill of materials (BOM), supplier capacity, lead time, and logistics capacity to generate material plans for each factory.

This linear information flow had limitations, as interruptions in later phases were challenging to rectify easily.

While this process is highly efficient under stable supply conditions, it encounters challenges when disruptions occur in later phases. For instance, a sudden shift in marketing preferences can prompt changes in the demand plan, leading to swift updates in supply and material plans. However, when material shortages arise from the demand side, OEMs tend to focus solely on adjusting material plans, leaving the demand plan unchanged. Typical measures in such situations include increasing safety stock, changing transportation modes for shorter lead times, urging suppliers to prioritize backlog resolution, utilizing alternative parts, and implementing retrofits afterward. Although these measures can mitigate short-term production disruptions, they often result in significant operational cost increases. This approach is effective mainly for minor supply interruptions, which were more common before the pandemic compared to serious crises.

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The limitations of this traditional process became evident soon after the pandemic began, as supply interruptions became more severe. Measures taken solely from the supply chain side were insufficient to address the escalating problems, necessitating actions from the supply plan side. Concurrently, pandemic-related labor issues affected production capacities, prompting adjustments in the supply plan. OEMs implemented measures such as reallocating production volumes among sites based on labor and stock levels. In this scenario, pipeline and finished goods stocks from suppliers were viewed as shared assets among factories, leading to material planning at the corporate level rather than the factory level.

However, despite the substantial supply challenges faced by OEMs during the pandemic, there were limited instances where demand plans were adjusted based on supply status. OEMs primarily adjusted demand plans in response to changes in customer demand forecasts, which were frequent during the pandemic. These adjustments flowed through the three planning steps but did not fully address the key issues faced by companies, namely, increased operational costs and order delays.

In the post-pandemic era, OEMs have conducted a thorough review of the supply chain-related changes and responses during the pandemic, identifying significant issues in the planning process. They discovered that the flow planning process was unable to detect conflicts between supply and demand effectively. In this process, the demand plan typically receives input solely from the market, with a greater focus on sales than on ensuring adequate supply. However, when supply becomes a bottleneck, the planning process requires additional information flows, transitioning it from a linear flow to a more interconnected web-like structure.

> *"One of the biggest problems is that production plans are often changed at the last minute. Sometimes, I feel like the marketing team doesn't understand the concept that part supply is not unlimited. We need to make the planning process more rational." (Supply Chain Vice President, OEM)*

To address these challenges, OEMs are developing a new planning flow in the post-pandemic era, where material supply constraints directly impact demand planning. By integrating supply information into the demand planning stage, OEMs can devise optimized solutions to allocate supply resources according to customer demand. This approach leads to more reasonable production schedules and material requirements, resulting in cost savings in operations and logistics. However, these changes in the planning process necessitate adjustments in organizational structure, KPI design, and information systems. They also bring about shifts in culture and power dynamics among teams involved in the planning process.

Despite the potential benefits of these planning process changes, concerns have been raised. Some argue that incorporating material supply constraints into the demand plan may hinder the plan from accurately reflecting market conditions. As a response, some OEMs are separating demand forecasts purely based on market information as a preliminary step before the demand plan, allowing them to track market demand changes while addressing supply constraints separately. This approach enables companies to maintain visibility over market demand fluctuations while managing supply-related challenges effectively.

4.3.3 Supply Chain Crisis Triggers Culture Changes

Culture plays a pivotal role in shaping the trajectory and outcomes of supply chain strategy transformations. A successful transition hinges on a culture that empowers the supply chain and fosters organizational acceptance of transition-related changes. During the pandemic, cultural shifts occurred at various levels, contributing to an environment conducive to supply chain strategy transformation. Within the supply chain department, there was a shift towards a more flexible work culture, emphasizing the importance of information connectivity. Research findings indicate an increased power and positive inter-departmental cultural shift within OEMs. Simultaneously, a corporate culture embracing change and openness emerged, laying the foundation for feasible supply chain strategy transformation. This transformation, in turn, reinforces these cultural changes.

Within the supply chain department, the working culture is evolving towards greater flexibility. This adjustment involves revising or even bypassing traditional processes to enhance agility during crises. Tasks are now prioritized and categorized, granting employees more decision-making authority based on their judgment rather than requiring approval from supervisors for certain tasks. For instance, given the significantly higher cost of air freight compared to sea freight, some OEMs necessitate senior operational manager approval for all air freight. However, during the pandemic, a list of emergency materials was established, allowing supply managers to bypass the approval process for critical materials on this list. Additionally, due to time constraints, meetings are now conducted more promptly, with fewer rounds of meetings before final decisions are made. This change in meeting formats has significantly increased information sharing among supply chain teams, fostering a more collaborative environment.

From an inter-departmental perspective, there is an emerging trend of increased power within the supply chain. This shift is primarily due to two reasons. Firstly, the supply chain department has become the focal point for managing scarce resources to address corporate bottlenecks. Consequently, the department's work directly impacts the performance of other departments, prompting greater cooperation and support from them for collective benefits. Secondly, the supply chain department has evolved into a central hub of information within OEMs. The supply crisis compelled the department to establish robust communication channels with previously weakly linked departments, resulting in the development of trust, accountability, and credibility through relationship building.

The control of scarce resources and the enhanced reputation garnered through networking have augmented the power of the supply chain department. Traditionally, internal clients of the supply chain team, such as production, R&D, and quality teams, held dominant power due to their positions. However, since the pandemic, there has been a slight shift in power dynamics, exemplified by the emergence of a ‘respect lead-time’ culture.

> *"The way we collaborate with R&D colleagues has undergone significant changes. Before COVID-19, rush orders from R&D were commonplace. Sometimes, they would place orders with only three days' notice and disregard our input entirely. Now, they understand the time required for transportation, and when we inform them of supplier capacity issues, they acknowledge the implications and adjust accordingly." (New Product Supply Manager, OEM)*

At the corporate level, the pandemic has significantly heightened companies' awareness of environmental dynamics, leading to a more adaptable corporate culture. This shift is primarily driven by the necessity for OEMs to break free from routine processes and swiftly respond to unprecedented challenges. These challenges extend beyond the purview of the supply chain function, encompassing shifts in customer preferences, government relations, and even production methods. The pandemic accelerated changes across all facets of operations, ranging from sales to aftersales service, procurement to assembly, and from supplier management to government relationships. These intensive changes brought about both risks and opportunities for OEMs, compelling them to adapt swiftly to mitigate risks and capitalize on opportunities—a collective understanding that permeates throughout the organization.

This culture of adaptability and proactive response is relatively novel within the automobile industry, which has historically been regarded as mature and relatively slow to embrace change. The newfound openness within organizations not only fosters resilience but also makes supply chain strategy transformation not just viable but imperative in navigating the evolving landscape successfully.

However, concerns persist regarding the durability of this open culture in the post-pandemic era, as the catalysts for these cultural changes were viewed as one-off situations. Based on findings of this research, the open corporate culture is expected to endure longer than the intra-departmental closeness, with changes in power dynamics at the inter-departmental level being the most susceptible to fading. When devising supply chain strategy transformation roadmaps, OEMs must consider this scenario and determine the optimal timing and sequence for implementing initiatives.

4.3.4 Vendor Management Method Update in Response to New Power Dynamics

The automotive industry faced various supply crises during the pandemic, prompting a reevaluation of the OEM-vendor power dynamic. Supply shortages during the pandemic bolstered the influence of suppliers. Given the intricate layers of the automobile supply chain, OEMs found it impossible to directly engage with all suppliers affected by material shortages, relying instead on tier-1 suppliers for information. This situation necessitated a shift towards a more transparent approach to supply chain management. Temporary but highly effective communication channels were established during the Covid-19 pandemic to address supply chain disruptions. Routine processes were formalized along the supply chain to enhance visibility, and responsibilities for data accuracy were redefined to encourage data sharing. This dual-directional transformation involved vendors sharing capacity and supply information while OEMs reciprocated with demand information. While communication tools facilitated this transformation, the underlying prerequisite for this enhanced management method was a sense of mutual benefit and trust. Leveraging increased visibility, OEMs are keen on integrating this trend into their post-pandemic supply chain strategies.

> *"Vendors were willing to share stock and capacity information because they knew we were facing material shortages and wouldn't exploit their data." (General Manager, OEM)*

> *"They didn't share stock information with us because it was unnecessary and they might worry that doing so would put them in disadvantage. But nobody was in the mood to worry about that during the pandemic when survival became the main goal… It is the same the other way round, we (OEMs) started to share long-term production plans with them (vendors)." (Inventory Control Manager, OEM)*

Simultaneously, suppliers, often serving multiple clients, gained more control over production capacity allocation, thereby influencing clients' production plans. This shift in the OEM-vendor relationship not only inflated material costs but also necessitated increased efforts by OEMs to maintain favorable relationships with these suppliers. As supply crises persisted, new processes and routines emerged, expected to endure in the immediate post-pandemic period. Another factor contributing to the new OEM-vendor dynamic was the bankruptcy of numerous small or medium-sized suppliers during the pandemic. This consolidation of the market empowered surviving suppliers with heightened bargaining power, though this effect is anticipated to revert to normal post-pandemic.

The evolving OEM-vendor power dynamic spurred automobile OEMs to revamp their vendor management methods, a pivotal aspect of their supply chain strategy transformation. Interviews revealed major changes, including risk migration to suppliers and deeper supply chain mapping, aligning with emerging resilience principles in supply chain strategy.

OEMs frequently encountered challenges with rigid supply chain structures, especially in adapting to sudden demand shifts or unforeseen disruptions, which intensified during the pandemic. The emergence of a more transparent OEM-vendor relationship during this time encouraged OEMs to shift risks to vendors by negotiating higher tolerance for order changes and more flexible terms within the order firm zone. While this change may initially incur additional costs and face resistance due to shifts in power dynamics, some OEMs anticipate that agility will become a widely accepted trend in supply chain management, ultimately leading to positive long-term returns on investment.

Another shift in vendor management involves deeper supply chain mapping. While supply chain mapping was a pre-pandemic trend (Fine, 2010), it wasn't a top priority in OEMs' strategies. However, the supply crisis compelled OEMs to prioritize mapping practices, recognizing the interconnectedness and interdependencies within the supply chain ecosystem. This trend persists post-pandemic, with OEMs expanding vendor sourcing criteria to include geographical locations, sourcing structures, and political and environmental contexts of deeper-tier suppliers. This deeper mapping enhances visibility and resilience by proactively addressing potential risks across multiple tiers of the supply chain.

4.3.5 Partnership Strengthens Control of Upstream Core Resources

One important lesson learned during the pandemic is that controlling upstream resources is key to building resilient supply chains. OEMs are designing initiatives to strengthen partnerships to secure control of critical materials, an integral part of supply chain strategy transformation. This trend, which emerged prior to the pandemic, has gained increased importance in the post-pandemic era. Although partnerships vary widely and depend on the circumstances of major stakeholders, two major types of partnerships have emerged: partnerships between OEMs and suppliers and partnerships between different OEMs.

Partnerships between OEMs and suppliers

There are generally two types of partnerships between OEMs and suppliers. The first type involves OEMs building relationships with established vendors, a practice that was already common but has become increasingly prevalent under the electrification trend. OEMs often engage in long-term business with these suppliers and may invest in joint R&D for key components. This helps OEMs secure a stable supply of materials and assists suppliers in securing stable orders. For instance, General Motors partnered with LG Chem in America to secure battery supply for GM EVs, while Tesla partnered with Panasonic in Japan to secure competitive battery prices. However, these partnerships are typically not exclusive. OEMs may have partnerships with multiple engine suppliers, and engine suppliers may work with multiple OEMs. Therefore, these relationships cannot guarantee top priority during crises, except in a few cases led by major OEMs like Volkswagen and Bosch.

Another type of partnership involves OEMs investing in electric software and hardware startups, a trend that has surged with the electrification trend. Instead of focusing solely on financial returns, OEMs view these partnerships as crucial for staying updated with new market technologies. This approach also helps OEMs establish strong relationships with emerging key-component suppliers from early stages. For example, BMW has partnered with Solid Power, a company developing solid-state batteries for electric vehicles, to explore advanced battery technologies. Similarly, Toyota's investment in Aurora Innovation, a self-driving technology company, aims to integrate autonomous technology into Toyota's electric vehicles, enhancing their capabilities and competitiveness.

However, there may be conflicts between the short-term returns expected by OEMs and the long-term growth needed by startups. Startups often require years to mature, which may not align with corporate venture capitalists' expectations of rapid returns.

Partnerships between OEMs

During the challenging times of the pandemic, OEMs began partnering with their competitors—a difficult yet highly efficient strategy to enhance supply chain resilience. These partnerships were initially formed to create synergy in R&D or marketing before the pandemic. However, the focus shifted during the pandemic towards allocating critical resources, driving partnerships between OEMs.

Given the substantial investments in breakthrough technologies in the automotive industry, OEMs often collaborate with other OEMs to leverage R&D resources and create synergies. For instance, General Motors and Honda are jointly developing autonomous driving technology. OEMs also tend to partner with local OEMs when entering new markets. For example, Ford partnered with Mahindra Group, an Indian multinational automotive manufacturer, for product development, technology sharing, and distribution in India. Additionally, OEMs collaborate to develop specific car models for niche market segments. For instance, Toyota and Subaru collaborated on sports cars like the Toyota 86 (GT86) and Subaru BRZ, which proved highly successful.

A unique type of partnership emerged during the pandemic due to supply crises. As different OEMs use parts from the same suppliers, some OEMs partnered to allocate scarce critical materials to the most profitable car models. For instance, BMW and Volkswagen partnered to ensure optimal allocation of semiconductor materials. This trend is expected to continue in the post-pandemic era to enhance supply chain resilience.

However, partnerships between OEMs require high standards from both parties. Unlike acquisitions, companies forming partnerships ideally have similar competitive strengths, such as brand recognition. Overlapping business interests should be minimal to prioritize collective benefits over individual corporate interests. Furthermore, partnered companies should have synergy in their operational systems, including R&D projects, production methods, suppliers, and logistics networks. These three perspectives are critical for the success of partnerships between OEMs, making them the most challenging type of partnerships.

4.4 Challenges in Supply Chain Strategy Transition

Although OEMs made adjustments to their supply chain strategy during the pandemic, either forced or proactive, the strategy transformation in the post-pandemic era still presents challenges to these companies as it introduces new talent requirements and encounters resistance to change.

4.4.1 Management and Technology Talent are at Urgent Need

The supply chain strategy transformation in the post-pandemic era brings new talent requirements, including in supply chain, technology, and management roles. Firstly, as the supply chain becomes increasingly crucial as an information hub for corporate operations, supply chain employees need to handle more coordination work. Talents for these coordination positions can come from external hires who demonstrate strong teamwork abilities or experienced colleagues who transfer from other teams. Companies also provide training to supply chain employees to enhance their coordination skills. For example, Mercedes-Benz introduced the Supply Chain Academy training program to assess all supply chain employees based on tailored matrices for different positions. Employees receive general training to understand the roles and responsibilities of all supply chain functions and personalized training to bridge any skill gaps.

In addition to talent quality, the strategy transformation requires larger supply chain teams due to the increasing number of suppliers. This necessitates more employees for management purposes. Initiatives like the new vendor management model mentioned in session 4.3.4 cannot scale universally due to deviations from established processes, leading to a need for more vendor managers. This trend is expected to persist in the early stages of the transformation but may fade with the implementation of supply chain simplification initiatives.

Technology talents are also crucial for implementing new supply chain strategies, given the evolving ways of acquiring, managing, and utilizing data. OEMs are undertaking digitalization projects such as smart warehouses, digital labeling systems, and digital supply chain mapping to enhance data transparency and traceability. Talents with expertise in these technologies are essential. Furthermore, the influx of data from these projects, additional interactions in new communication channels, and more layers in supplier networks all require talent in data storage, processing, and analytics. From an application perspective, talents are needed to extract value from data, with advanced technologies like artificial intelligence requiring specific skills in areas such as demand forecasting and logistics optimization.

In addition to supply chain and technology talents, emerging supply chain strategies also demand multi-talented individuals with expertise in both supply chain and technology for management roles. While positions like product managers, project managers, and internal strategic consultants are not new, their proportion has increased in the post-pandemic era as supply chains transition towards resilience, agility, and simplicity. Many OEMs are witnessing a rise in digitalization projects, creating demand for individuals with diverse skill sets.

Despite a growing trend in talents with desired capacities, there is still a shortage of talent supply in the near future due to a lag in talent training and immediate demands from OEMs. OEMs require talents now to support supply chain transitions while ideal fresh talents are still in the education pipeline. Additionally, the increase in supply chain team size and talent quality leads to rising labor costs, one of the biggest challenges for supply chain transformation, especially amid increasing operational costs and a challenging global economic situation post-pandemic.

4.4.2 Change-Resistant Culture Brings Risk to Transformation

Another challenge in supply chain strategy transformation is the culture resistant to change. Although the culture within OEMs is shifting towards openness, flexibility, and connectivity at intra-departmental, inter-departmental, and corporate levels, resistance to change still persists. This culture is particularly entrenched in large hierarchical organizations like OEMs, posing significant challenges to transformation efforts (Chukwuma, 2022). The change-resistant culture has experienced shifts, as depicted in Figure 4. There are 2 major challenges from the culture perspective that might affect supply chain strategy transformation.

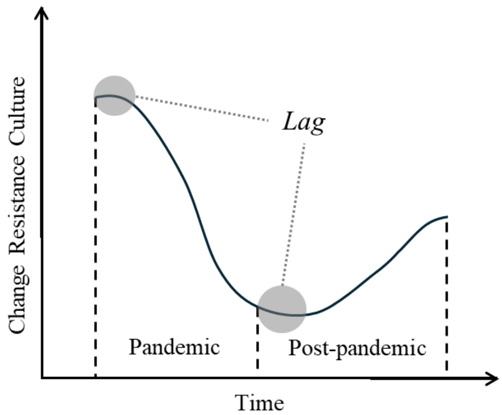

Figure 4. Change resistance trend since the pandemic.

Firstly, there is a clear trend indicating the resurgence of this culture after the pandemic. As borders and transportation routes resumed operations post-pandemic, the issues of long lead times and material supply uncertainties eased significantly. Although challenges like semiconductor shortages continue post-pandemic, their uncertainty is considerably reduced. Consequently, OEMs are facing decreased supply chain pressures, and operations are generally returning to normal. The resurgence of the change-resistant culture coincides with efforts to reform routine processes and hierarchies, posing a conflict with the open and flexible culture necessary for supply chain strategy transformation. Addressing this entrenched culture within a short timeframe poses a significant challenge and may impede the quality and pace of transformation efforts.

Additionally, changes in culture have resulted in varying degrees of lag in reaction during two phases: the initial stages of the pandemic and immediately after its termination. Companies exhibited different sizes and durations of these lags during these phases. The lag was shorter at the onset of the pandemic due to severe pressures faced by companies. The lag post-pandemic termination is expected to persist longer. This phenomenon has led to a disconnect in executing supply chain transformation initiatives between the pandemic and post-pandemic eras. Post-pandemic, there is a tendency to overlook lessons learned from the pandemic, with a belief that processes or habits induced by the pandemic were temporary. Planned initiatives, along with existing ones, have slowed down post-pandemic, raising concerns about their implications on supply chain strategy transformation.

> *"The inertia in culture delayed the transformation. Some departments, like finance, were less affected during the pandemic and exhibit the largest inertia." (Corporate Strategy Consultant, OEM)*

Initiatives changed at different speeds across departments. The supply chain department, at the forefront of supply crises, experienced smaller lags at the pandemic's onset. The change-resistant culture remains relatively subdued at the current stage but is recovering slowly. Conversely, departments that are internal clients to the supply chain department, such as R&D, manufacturing, and quality management departments, are experiencing a moderate-speed rise in change-resistant culture. Supporting departments like human resources and finance have quickly resumed this culture. Departments farther from the supply chain department in the network have fewer direct connections to supply chain strategy transformation and experience a quicker resurgence of the change-resistant culture. However, support from all departments is crucial for implementing supply chain strategy transformation. OEMs must find solutions to mitigate the impact of this culture by continuously motivating departments further in the supply chain department network.

5. CONCLUSION

5.1 Summary of Findings

This research has focused on the transformation of supply chain strategies among automobile OEMs in the post-pandemic era, recognizing the enduring impact of supply chain crises during the pandemic. The findings underscore that the motivation for supply chain strategy transformation in this era is distinct from previous transformations, largely driven by external factors such as the electrification trend, geopolitical events like the Ukraine-Russia conflict, and the COVID-19 pandemic itself. The electrification wave has necessitated collaboration with new suppliers for electric vehicle components, while geopolitical events and trade disputes have disrupted supply chains and transportation routes. The pandemic emerged as the primary catalyst, causing material shortages, demand fluctuations, production disruptions, and escalating costs.

These challenges have emphasized the paramount importance of supply chain resilience, leading to initiatives such as increased safety stock, dual-sourcing critical materials, and enhanced collaboration and visibility with suppliers. Organizational changes have accompanied this transformation, including the creation of roles like critical supply managers, empowering procurement departments for agile sourcing, and involving supply chain teams earlier in product development. Planning processes have been overhauled to integrate material supply constraints into demand planning, fostering a more holistic approach. Cultural shifts promoting flexibility, openness to change, and increased influence for supply chain functions have occurred across intra-departmental, inter-departmental, and corporate levels. New vendor management methods, such as deeper supply chain mapping and risk-sharing with suppliers, have also emerged. Partnerships between OEMs and suppliers, as well as among OEMs themselves, have been reinforced to secure control over critical upstream resources, particularly for electric vehicle components.

However, challenges persist, including talent shortages for supply chain, technology, and multi-skilled roles, as well as resistance to change, particularly in supporting departments less directly impacted by supply chain disruptions.

5.2 Practical Implications

5.2.1 Insights on Post-Pandemic Supply Chain Transformation Trends

The findings of this research provide invaluable insights into the major trends shaping automotive supply chain transformations in the post-pandemic era, serving as a strategic compass for industry players navigating this complex landscape of change. By distilling lessons learned from disruptions, companies can proactively reallocate their limited resources to align with emerging opportunities. This trend overview equips automobile OEMs and industry stakeholders to craft more resilient and future-ready transformation roadmaps.

Moreover, the impact of these trends extends beyond OEMs to encompass the entire automotive ecosystem. Logistics service providers must recalibrate their strategies to embrace localization trends and adapt to the emergence of new supplier clusters. Tier-1 and tier-2 suppliers face heightened demands for resilience, necessitating proactive measures to enhance their capabilities. Startups find increased collaboration opportunities with industry leaders, leveraging resources through strategic partnerships. As OEMs seek greater supply chain control, suppliers must rethink client management strategies while safeguarding core interests.

Governments can leverage these insights to formulate policies stimulating industry growth more effectively. By offering an in-depth analysis of supply chain strategy trends, this research serves as a valuable reference for industry players, catalyzing transformative changes across the automotive landscape.

Additionally, the research sheds light on the digital transformation journey of automotive supply chains, reshaping traditional operations and fostering collaboration among stakeholders.

In essence, the comprehensive analysis provided by this research not only aids in understanding current trends but also paves the way for future innovations and strategic directions in the automotive supply chain domain, underscoring the imperative for continuous adaptation in a rapidly evolving landscape.

5.2.2 Guidance on Navigating Anticipated Challenges

This research identifies and provides guidance on critical challenges companies will likely face during supply chain transformations, such as talent shortages and cultural resistance to change. Recognizing these challenges upfront allows companies to proactively develop strategies to overcome them, leading to improved operational efficiency, reduced risks, enhanced adaptability, and increased competitiveness.

Furthermore, this research outlines a practical roadmap for automakers to strategically leverage and allocate organizational resources in navigating these anticipated challenges. By adopting digital technologies, fostering cross-functional integration, nurturing collaborative supplier ecosystems, and exploring potential industry consolidation plays, companies can innovate within the automotive industry and successfully navigate challenges.

By aligning supply chain strategies with broader business objectives and market trends, companies can ensure transformations lead to sustainable long-term success. This proactive and strategic approach allows companies to mitigate risks and capitalize on growth opportunities in the evolving automotive landscape.

In summary, this research offers automotive companies a robust guide to navigate complexities, enhance supply chain resilience, and future-proof operations, catalyzing meaningful transformation initiatives.

5.3 Recommendations

To successfully navigate supply chain strategy transformation in the post-pandemic era, it is beneficial for automotive industry players to prioritize the following recommendations.

5.3.1 Develop Management, Technology and Hybrid Talents

Automobile OEMs can adjust their talent management strategy for supply chain functions by building relocation programs and stimulate talents joining the supply chain function. Investing in developing a robust talent pipeline for supply chain roles can provide a competitive advantage. Comprehensive internal training programs that upskill existing employees across procurement, logistics, and operations can be valuable. Rotational initiatives enabling talent cross-pollination across functions foster vital knowledge sharing.

Additionally, enhancing employer branding to position supply chain careers as strategic and technology-driven roles is recommended. Partnering with academics for tailored curricula, internships and recruitment can help attract top talent from fields like data science, engineering and analytics into these roles.

Another important talent management principle to cope with the supply chain strategy transformation is allocating the right talents to the right positions at the right time as strategic deployment aligned to transformation roadmaps is prudent. Different phases necessitate a mix of change management, process redesign, digital skills and supplier relationship management expertise. Establishing flexible talent deployment models that map skill needs to milestones enables timely access to niche expertise as required, preventing shortages from impeding progress.

While building comprehensive talent strategies requires upfront investments in training, recruitment and rotation programs, the long-term benefits of a skilled, future-ready supply chain workforce well-equipped to drive transformation cannot be overstated.

5.3.2 Make Good Use of the Lag in Culture-Resistant Culture Change

The findings reveal a window of opportunity for supply chain transformation stemming from the lag in change-resistance cultures, particularly in support functions less disrupted by the pandemic. Swiftly capitalizing on this openness to new ways of working while resilience-minded cultures prevail is strongly encouraged.

Prioritizing and frontloading strategic, enterprise-wide transformation initiatives like restructuring supply chain teams, deploying digital capabilities or realigning planning processes can accelerate the change momentum before cultural inertia regains its grip. Automotive leaders should couple this prioritization with robust, multi-pronged change management programs to reinforce and deeply entrench the new resilient operating models.

5.4 Limitations and future research

The scope of this study was deliberately confined to examining the dynamics between OEMs and tier-1 suppliers within the automotive industry. While this focus has yielded valuable insights into supply chain strategy transformations, a more expansive analysis could be achieved by incorporating tier-2 suppliers and other related players in the ecosystem. By including these additional stakeholders, future research could explore the intricate relationships, dependencies, and collaborative efforts that shape the modern automotive supply chain landscape. This deeper examination would provide a more comprehensive understanding of the challenges and opportunities inherent in supply chain transformations across multiple tiers of the industry.

Furthermore, it is essential to acknowledge that this research, while laying out a strategic roadmap for supply chain strategy transformations, cannot immediately offer an evaluation of the outcomes of the initiatives outlined in the roadmap session. The nature of transformation initiatives is such that their full impact and effectiveness often become evident over time, requiring a longitudinal study approach. Follow-up research endeavors could be directed towards assessing the long-term effects of these initiatives on operational performance, cost efficiency, customer satisfaction, and overall business resilience. Such evaluations would provide valuable insights into the efficacy of different transformation strategies and help refine future approaches based on empirical outcomes.

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APPENDIX

Appendix 1: Interview Questionnaire

Motivation

1) What major challenges did your company face in its supply chain during the crises of the past 5 years?
2) What strategic changes did you enact to address these challenges?

Timing

1) When did your company begin making long-term changes in response to the global supply chain crisis?
2) Do you have a transformation roadmap for supply chain strategies? What are the key phases and strategic priorities?

Roadmap

1) What are the main objectives driving your supply chain transformation efforts?
2) How has the strategy transformation impacted power, structure, and culture within your organization so far?
3) How does your evolving supply chain strategy align with and support the company's broader strategy?
4) Do you anticipate these supply chain transformation trends continuing post-pandemic? Why or why not?

Method

1) How is your organization managing the changes in supply chain strategy?

2) What has been the evolution or journey of your supply chain strategy? What process do you use to define strategic changes at each stage of the transformation journey?
3) Do you tailor strategies by supplier or component? How do you categorize suppliers, and can you provide examples of how your strategy has changed for specific ones?
4) How has your supply chain footprint changed geographically, and how might it continue to evolve? What factors shape location decisions?

Challenges

1) What have been the biggest challenges or sources of resistance - internal or external?
2) Which teams struggled most to adapt? What were the reasons behind resistance?
3) What steps did you take to mitigate resistance, and were they effective?