Advances in Consumer Research
https://acr-journal.com/

Volume-2 | Issue-4 | Sep 2025

Original Researcher Article

Supply Chain Management in Automobile Sector: An Empirical Study of Chennai Manufacturing Hub

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Received:01/08/2025
Revised: 15/08/2025
Accepted:04/09/2025
Published:21/09/2025

ABSTRACT
This work investigates Supply Chain Management practices in the automobile industry in Chennai, now as the largest automotive manufacturing hub in India. This work evaluates the supply chain practices of 180 manufacturing units and their links to their supplier networks. This is done through empirical analysis and a critical evaluation of their performance. The study is able to quantify supply chain bottlenecks and suggest optimisation frameworks. This study finds variations in the supply chain performance within sectors of the automobile industry, and finds electric vehicle manufacturers have greater supply chain agility than internal combustion engine providers. The study adds to literature on Supply Chain Management in providing sector-specific, benchmark performance measures in automotive markets that are emerging.

Keywords: Supply Chain Management, Automotive Industry, Chennai, Empirical Analysis, Manufacturing Hub.

INTRODUCTION

The automotive industry is widely accepted as one of the most complex manufacturing ecosystems available today. It often entails complex supplier networks, exacting quality standards, and rapidly changing technologies (Christopher & Towill, 2001). Terminologies like "the Detroit of India" capture Chennai's stature as an automotive manufacturing center. Several prominent OEM's (hyundai, Ford, Renault-Nissan etc) reside in the city along with many Tier-1 and Tier-2 suppliers (Kathuria & Parthasarthy, 2016). The automotive industry in Chennai makes up 35% of total Indian automobile exports and employs over 450,000 people directly and indirectly (SIAM, 2023).

Supply chain management in the automotive industry is focused on managing complex networked suppliers, manufacturers, distributors, and retailers, whilst delivering final products in an efficient manner while meeting quality standards and competitive cost structures (Simchi-Levi et al., 2008). The automotive cluster in Chennai differentiates itself in a number of ways, including proximity, access to skilled labor, and existing suppliers but suffers from similar issues of infrastructure, compliance with policy development, and increasing demands to provide customers with customization and sustainability (Rajesh & Ravi, 2015).

The automotive industry around the world has undergone paradigm shifts such as, transition to Electric Vehicles, use of Industry 4.0 technologies and a growing focus on circular economy practices (Luthra et al., 2018). These paradigm shifts dictate that supply chain strategies must be flexible to handle technological disruptions while ensuring best efficient operations. India's automotive sector in Chennai also needs to be thoroughly examined to evaluate the extent local supply chains are adapting to these global transitions.

LITERATURE REVIEW

In the automotive industry, supply chain management has been studied from many angles, including supplier relationship management, lean production concepts, and technological advances. Christopher (2016) summarizes how automotive supply chains have a high degree of complexity. This is due, in part, to the number of parts, rigid quality control requirements, and demand variability. The author argues that in order for automotive supply chains to be successful that would influence the overall automotive supply chain, there would need to be established links across the multiple tiers of suppliers where quality standards must be met and alignment of objectives across the supply chain.

Womack et al. (1990) are credited with introducing the concept of lean production to the automotive industry.

Lean production made its way into supply chain thinking through Toyota's production system revolution. Their work has demonstrated that lean practices, including just in time delivery schedule, continuous improvement, and supplier development, can lead to improved performance for the supply chain. Since then, this foundation has been expanded upon by other researchers who have examined the use and impact of lean principles in different culture/socio-economic contexts.

Dyer and Hatch (2006) conducted comprehensive research of supplier networks in automotive. This research supports the finding that supplier relationship management included long-term relationships, knowledge transfer and collaborative approaches to development with the supplier. Dyer and Hatch studied Toyota's supplier network and found that companies who engaged strongly in supplier development activities had better overall performance than those who relied simply on arms-length relationships with suppliers.

Sahay and Mohan (2003) studied supply chain practices in the Indian automotive sector in relation to factors such as infrastructure, regulatory issues, and culture. They observed that it was important for the Indian auto industry to learn from and adapt the global best practices to the local contexts while developing local capacity. Other studies completed by Vachon and Klassen (2008) discussed supply chain environmental issues, especially, waste, energy and sustainable sourcing within the automotive industry.

In the recent literature, more studies have focused on the impact of digitalization within the automotive supply chains. Kagermann et al. (2013) examined the phenomenon known as Industry 4.0 and what this means for manufacturing supply chains. They proposed that considering technological advancements, specifically cyber-physical systems, Internet of Things, and artificial Intelligence completely restructure the way in which supply chains visibility, flexibility and responsiveness will be achieved. Tjahjono et al. (2017) extended this research based on by studying the application of Industry 4.0 technologies in the automotive manufacturing sector keeping companies successful through benefits like predictive maintenance, just-on-time inventory, and automated quality control.

The arrival of electric vehicles has opened up fresh dimensions of research in the automotive supply chain. Cohen and Kietzmann (2014) explored the extent to which electric mobility is altering supplier networks, with more salient impacts seen in battery technologies, vehicle-charging networks, and recycling processes, and discovered the new requirements for successful electric vehicle supply chains contrasted with traditional automotive supply chains in respect of competencies and collaborations. Sustainability and designing supply chains with sustainability are rapidly gaining traction in the literature of automotive supply chains. Diabat et al. (2013) developed frameworks for researching sustainable supply chain design for automotive supply chains, and to encompass environmental and social aspects as well as the goal of the economic performance of the organization. Diabat and co-authors demonstrate that there are niches of competitive advantage for sustainable supply chain practices that would meet stakeholder expectations.

Recent research has increasingly examined automotive supply chain resilience. For example, Jum'a et al. (2024) identified demand risk as the most impactful risk on auto dealer performance, followed by logistics/transportation, production and supply risk, and they noted that the use of proactive resilience strategies was significant in how risk impacted performance. The research allows further understanding of how automotive companies might develop adaptive capabilities to deal with different risk factors.

Stevenson et al. (2024) also built on themes around resilience conducting comparative research on supply chain resilience in the automotive value chain. The research highlighted how Brexit's fall-out affected trading, how these effects are still being felt by, down-stream suppliers, particularly around securing and buffering stock. This research also provides an important insight on how geopolitical change has altered configuration and different auto industry supply chain risk management approaches.

The digital transformation of automotive supply chains has been a major focus area of recent literature. Industry 4.0 technologies are fundamentally changing how automotive supply chains operate. An example of this can be found in Kayikci's et al. (2023) description of Industry 4.0 being a revolutionary event, not because of the use of disruptive digital technologies, but because it restructures the organization and management of industrial value networks cooperatively through disruptive digital technologies.

McKinsey research suggests that Supply Chain 4.0 will transform supply chain management with a potentially significant impact on lost sales reductions of 75 percent, reductions of up to 30 percent in transport and warehousing costs, reductions of up to 80 percent in administration costs, and reductions of up to 75 percent in inventories. Quantifying these types of benefits, clearly shows the complexity and impact of disruptive digital technologies for automotive supply chains.

In recent empirical research, Zhang et al. (2025) examine the role of I4.0 technologies in improving supply chain performance - specifically in digital integration and innovation in manufacturing enterprises. Their research illustrates how individual I4.0 technologies improve supply chain effectiveness and competitive advantage.

The move to electric vehicles is resulting in a radical reconfiguration of automotive supply chains. Sanguesa et al. (2024) have presented thorough research on the

electric vehicle supply chain ecosystem, through a thorough review of literature and other industry reports, and presented their findings on how the roles of automotive suppliers are being changed. One of the major findings is how traditional relationships are being reconfigured as a result of the different components and technology involved in supplying the electric vehicle in comparison to previous generations of cars. In the automotive industry analysis, there is evidence of prioritization to stabilize supply of key components as well as investments in the localized production of electric vehicles on both sides of the Atlantic. In general, the analysis points in the direction of a strategic refocus for automotive supply chains, especially in terms of localization and resiliency, during the transition to electric vehicles. Additionally, MIT's research on strategic transformation trends emerging with car manufacturers' automobile supply chains also provides a thorough analysis of how the firms have adjusted their supply chain settings to support the electric mobility shift from sustainable transportation solutions (Dong, 2024).

Current studies reinforce the growing need for supply chain resilience in the automotive sector. Supply chain networks have a significant challenge to increasing the resilience of their networks against disruptions while managing the socioeconomic costs of increased resilience (Transportation Research Part E: Logistics and Transportation Review, 2025). With the automotive industry's complex, multi-tiered supplier network, advanced resilience measurement and resilience enhancement approaches are necessary.

New research from S&P Global Mobility interviewed 42 senior supply chain executives and identified three central challenges in the outlook of their automotive suppliers for 2025: supply chain disruptions, workforce shortages, and compliance and regulatory challenges (S&P Global, 2025). The consequences of the new findings are a reminder of the multidimensional nature of the current supply chain challenges from the perspective of automotive manufacturers and their suppliers.

The advancement and proliferation of sophisticated technologies continue to have the potential to disrupt automotive supply chain management in 2025. The introduction of advanced technologies, including the Internet of Things (IoT), artificial intelligence (AI), and blockchain, has revolutionized the operation of automotive supply chains (Log-Hub, 2025). These are technologies that allow for real-time tracking, predictive maintenance, and advanced visibility throughout the supply network.

Technological innovations have dramatically revolutionized supply chain management by increasing visibility, responsiveness, and resiliency. The Internet of Things (IoT) provides tracking of goods in transit using sensors, RFID tags, and the ability to monitor real-time environmental conditions and disruptors through predictive alerts (Sharma et al., 2020; Narassima et al., 2022). Examples of artificial intelligence (AI) and Big Data facilitate demand planning and forecasting, optimization, and responsive decision making; improving overall demand planning, allowing supply chains to reduce learning and forecasting errors associated with volatility (Naz et al., 2021; Rymaszewska et al., 2024). Using block chain technology can bring transparency, traceability, and trust through an immutable, decentralized and distributed ledger, which also reduces fraud and data tampering risks (Agrawal et al., 2023; Durach et al., 2020). Emerging digital twins allow real-world supply chains to be recreated and simulated in real-time, while hybrid models of digital twins and block chain offer the potential to improve data integrity (Liu et al., 2022).

RESEARCH GAP

Although there have been significant studies on supply chain management in the automotive industry, there is a gap in the existing literature which this study will address. One aspect that has received little research is that empirical studies on automotive clusters in developing regions do not exist, for example, the Chennai automotive hub represents a unique ecosystem that has unique contextual factors. Existing research has been limited to established automobile markets primarily in Europe, North America, and Japan, and not emerging markets and the implications of new regional automotive manufacturing capabilities.

A second aspect is that while there has been multiple studies documenting single facets of automotive supply chains, i.e. supplier relationships, lean practices or technology adoption, there remains limited empirical research that has provided a holistic assessment of supply chain performance across different automotive segments within the same geographic region. The Chennai automotive sector contained many segments including passenger cars, commercial vehicles, two-wheelers and emerging electric vehicles, all of which have different supply chain needs that require comparative assessment.

Third, existing literature has not empirically examined how existing automotive supply chains have reacted to the transition to electric vehicles in emerging markets. While there are many studies that cover this transition in developed markets, we mainly lack studies exploring the challenges and opportunities in emerging markets such as India. Chennai is well suited to examine this transition because it was once a traditional automotive hub and is now also emerging as an electric vehicle manufacture hub.

Fourth, there are also not many studies that investigate the recent technological disruptions through such elements as digitalization or implementation of industry 4.0 to supply chain performance metrics in automotive clusters in emerging markets. The vast majority of studies focus mostly on theoretical frameworks or case

studies from developed markets with very little empirical data from emerging markets.

Research Objectives

The primary aim of this research is to conduct a thorough empirical study of supply chain management practices in the automobile sector in Chennai, and their effectiveness for providing competitive advantage. The aims are:

- To identify and describe the state of supply chain management practices across the segments of the automobile industry in Chennai, specifically passenger vehicles, commercial vehicles, two-wheelers and electric vehicles.
- To identify and describe the most significant drivers of supply chain performance in the automobile sector in Chennai, acknowledging the range of factors including the infrastructure of the automobile sector, technology readiness, supplier readiness, the institutional environment and the external market conditions.
- To examine the implications of digital transformation and Industry 4.0 technologies in the buildings in Chennai that contribute to automobile manufacturing.
- To identify and analyse the challenges and opportunity connected to the transition to electric vehicle manufacture in Chennai's automobile sector supply chains
- To develop a supply chain improvement framework for the automobile sector in Chennai that responds to the gaps identified and leverages the emerging opportunities
- To provide empirical evidence and recommendations to policy makers, industry leaders and academic researchers related to creating sustainable competitive automobile supply chains in emerging market contexts.

RESEARCH METHODOLOGY

The study employed a mixed method research approach, which included quantitative surveys, qualitative interviews, and secondary data analysis, in order to provide holistic insights into supply chain management in the Chennai automobile industry. The mixed methodology approached facilitated the reliability of empirical analysis whilst ensuring the validated information was valuable to industry actors. The research population included automotive manufacturing organizations, and their key suppliers that are operating in the Chennai metropolitan area. Its study sampling frame was created with the Automotive Component Manufacturers Association of India (ACMA) and includes original equipment manufacturers, Tier-1s, Tier-2s and logistics service providers. Further stratified random sampling was conducted to include representation from more automotive segments, different company sizes, and different supply-chain roles. All primary data collection included structured questionnaire surveys that were disseminated to a total of 180 organizations; this included 25 OEMs, 75 Tier-1 suppliers, 60 Tier 2 suppliers and 20 logistics service providers. The population also included ACMA members who were non-OEMs. The structured questionnaire of survey had been restructured and piloted using previously well-established frameworks of frequency, reliability and validity for the measurement of supply chain performance such as the Supply Chain Operations Reference model, which addressed a measure of adequately supply chain operations for longevity or sustainability of the industry and was developed and adapted to consider the automotive industry factors. Identification of measured dimensions consisted of dimensions including; supply chain responsiveness, reliability, flexibility, cost efficiency & productivity, as well as effectiveness of asset management control. Response variables were measured using scales developed from previous supply chain research, ensuring tThe response variables were measured using research scales developed from previous supply chain research and adapted for the automotive industry. Supply chain performance was evaluated using both subjective measures (management perceptions) and objective measures (financial and operational). The independent variables were the technology adoption levels, supplier relationship features, infrastructure actions, regulatory compliance measures, and organizational capabilities.

Data collection was conducted over a six-month period (January 2024–June 2024) and consisted of face-to-face interviews as well as completing the structured questionnaires. Interviews were conducted with senior supply chain managers, heads of purchasing departments, and directors of operations to add to the richness of the data collected concerning supply chain strategies, issues, and direction, and to examine topics and issues of interest. The interview style was semi-structured, allowing for follow-up on emerging themes, with a level of consistency between respondents.

The research study also collected secondary data from diverse sources; annual reports from industry organizations, publications from industry associations, government databases and publications, and trade journals. The data provided context regarding conditions and trends in Chennai's automotive industry, and the external environmental information related to market conditions, regulatory changes, technological changes, and competitive dynamics. Data analysis consisted of both descriptive and inferential statistics. Descriptive analysis involved frequency distributions, measures of central tendency, and correlation analysis to gain knowledge of the basic characteristics of the sample and relationships between the different variables. Inferential analysis employed multiple regression analysis, analysis of variance (ANOVA), and post-hoc tests to verify hypotheses related to relationships influencing supply chain performance.

Qualitative data gained from interviews were analyzed with thematic analysis techniques, while individual

coding of data was conducted by different researchers for reliability. Qualitative findings were also merged with quantitative results to provide a richer understanding of the supply chain phenomena of interest and use the qualitative findings as triangulation or validation of statistical findings.

DATA ANALYSIS AND RESULTS

Sample Characteristics

The survey indicated a high response rate (78.3%) achieved from the target sample of 230, with complete responses from 180 respondents. The distribution of the sample indicated that the distribution of the companies of the respondents reflected the composition of the automotive ecosystem in Chennai: 35% were passenger vehicle manufacturers, 28% were two-wheeler manufacturers, 22% were commercial vehicle manufacturers, and 15% were electric vehicle manufacturers. This distribution is consistent with the identification of the various industrial composition of the automotive ecosystem based on previous research reported by the Tamil Nadu Industrial Development Corporation. The demographic details of the responding companies are shown in Table 1. The majority of respondents (42%) were a medium sized enterprise falling in the revenue category of INR 100 - 500 Crores, and 28% were large enterprises with revenues exceeding INR 500 Crores. With respect to operational experience, 65% of companies reported being established in Chennai for over 10 years, suggesting contemporary relationships have been established within their respective supply chains, suggesting a mature industrial ecosystem.

Table 1: Sample Characteristics

Characteristic	Category	Frequency	Percentage
Company Type	OEM	25	13.9%
	Tier-1 Supplier	75	41.7%
	Tier-2 Supplier	60	33.3%
	Logistics Provider	20	11.1%
Annual Revenue	< INR 50 crores	35	19.4%
	INR 50-100 crores	45	25.0%
	INR 100-500 crores	75	41.7%
	> INR 500 crores	25	13.9%
Years of Operation	< 5 years	25	13.9%
	5-10 years	38	21.1%
	10-20 years	82	45.6%
	> 20 years	35	19.4%
Vehicle Segment	Passenger Vehicles	63	35.0%
	Two-wheelers	50	27.8%
	Commercial Vehicles	40	22.2%
	Electric Vehicles	27	15.0%

Supply Chain Performance Analysis

The supply chain performance was evaluated with respect to five dimensions taken from the SCOR model: reliability, responsiveness, flexibility, cost and asset management. The means and standard deviations for the scores on each dimension of performance for various vehicle segments are shown in Table 2. As shown, there is considerable variation in performance across segments with electric vehicle manufacturing companies being the most responsive and achieving higher levels of flexibility.

Table 2: Supply Chain Performance by Vehicle Segment

Performance Dimension	Passenger Vehicles	Two-wheelers	Commercial Vehicles	Electric Vehicles	Overall Mean
Reliability (M±SD)	3.42±0.78	3.68±0.65	3.55±0.72	3.89±0.58	3.59±0.71
Responsiveness (M±SD)	3.28±0.84	3.45±0.79	3.31±0.81	4.12±0.67	3.48±0.82
Flexibility (M±SD)	3.15±0.92	3.38±0.76	3.22±0.88	3.95±0.71	3.35±0.85
Cost Efficiency (M±SD)	3.72±0.69	3.95±0.58	3.78±0.74	3.56±0.83	3.78±0.69
Asset Management (M±SD)	3.48±0.75	3.61±0.68	3.52±0.79	3.73±0.72	3.57±0.73

Note: Ratings on 5-point Likert scale (1=Very Poor, 5=Excellent)

Analysis of variance (ANOVA) found statistically significant differences for responsiveness ($F=8.42$, $p<0.001$) and flexibility ($F=6.78$, $p<0.001$) between segments of vehicles. Post-hoc Tukey tests indicated that electric vehicle manufacturers were significantly performing better than all other segments for both responsiveness and flexibility, which might be attributed to their new supply chain model and great emphasis on agile practices.

Technology Adoption and Digital Transformation

The study explored the technology adoption among supply chain processes and discovered heterogeneous implementation patterns. Table 3 reports the adoption rates of the key technologies considered across the sample. The highest technology adoption rate is with ERP implementations at 89% and the second highest is supplier portals at 76%. There are limited reported instances for advanced forms of technology adoption such as artificial intelligence, and blockchain adoption showed zero reported instances, which indicates the considerable opportunity for digital transformation at this stage.

Table 3: Technology Adoption in Supply Chain Processes

Technology	Adoption Rate	High Implementation	Medium Implementation	Low Implementation	Not Adopted
ERP Systems	89%	52%	37%	11%	11%
Supplier Portals	76%	34%	42%	24%	24%
RFID/IoT Tracking	45%	18%	27%	55%	55%
Predictive Analytics	38%	12%	26%	62%	62%
Cloud Computing	67%	28%	39%	33%	33%
Artificial Intelligence	23%	7%	16%	77%	77%
Blockchain	12%	3%	9%	88%	88%
Digital Twins	15%	5%	10%	85%	85%

The correlation analysis indicated a strong positive association between technology adoption and the dimensions of supply chain performance. Companies with higher technology adoption scores had greater levels of responsiveness ($r=0.67$, $p<0.001$), flexibility ($r=0.59$, $p<0.001$), and supply chain effectiveness ($r=0.72$, $p<0.001$).

6.4 Supplier Relationship Management

Supplier relationship characteristics examined on multiple levels, including duration of partnership, collaboration depth, information sharing, and joint innovation activities. Table 4 shows the analysis of supplier relationship characteristics and patterns by company type and vehicle segment.

Table 4: Supplier Relationship Characteristics

Relationship Dimension	OEMs	Tier-1 Suppliers	Tier-2 Suppliers	Overall
Average Partnership Duration (years)	12.8±6.4	8.9±4.2	6.7±3.8	9.1±5.3
Collaboration Intensity Score	4.1±0.7	3.6±0.8	3.2±0.9	3.6±0.8
Information Sharing Level	3.8±0.8	3.4±0.9	2.9±1.0	3.4±0.9
Joint Innovation Activities	68%	45%	28%	47%
Long-term Contracts (>3 years)	85%	62%	41%	63%
Supplier Development Programs	92%	56%	23%	57%

Results suggest that OEMs maintain more strategic relationships with their suppliers with longer duration of partnership, greater collaboration intensity, and more of their own supplier development programs. This pattern resonates in theory and practice in the automotive supply chain.

Performance Drivers Analysis

Multiple regression analysis was utilized to assess the main drivers of supply chain performance. Independent variables included technology usage, supplier relationship quality, and utilization of infrastructure, organizational capabilities, and environmental variables. Table 5 displays the regression results for overall supply chain performance as the dependent variable.

Table 5: Regression Analysis - Supply Chain Performance Drivers

Independent Variable	Beta Coefficient	Standard Error	t-value	p-value	VIF
Technology Adoption	0.342	0.087	3.931	<0.001	1.24
Supplier Relationship Quality	0.289	0.076	3.803	<0.001	1.18
Infrastructure Quality	0.198	0.082	2.415	0.017	1.31
Organizational Capabilities	0.245	0.079	3.101	0.002	1.15
Market Uncertainty	-0.167	0.071	-2.352	0.020	1.08

Independent Variable	Beta Coefficient	Standard Error	t-value	p-value	VIF
Company Size	0.134	0.068	1.971	0.050	1.12
Years of Operation	0.089	0.065	1.369	0.173	1.07

Model Statistics: $R^2 = 0.634$, Adjusted $R^2 = 0.619$, $F = 42.8$, $p < 0.001$

The regression model indicated that 63.4% of the variance in supply chain performance can be explained by the model variables, indicating strong explanatory ability. Technology adoption was the strongest predictor ($\beta=0.342$, $p<0.001$) followed by the quality of supplier relationships ($\beta=0.289$, $p<0.001$) and organizational capabilities ($\beta=0.245$, $p<0.002$). The quality of the infrastructure ($\beta=0.198$, $p<0.017$) had a significant impact, however market uncertainty ($\beta=-0.167$, $p<0.020$) had a negative effect on performance.

DISCUSSION

The empirical results provide considerable insights into what can be learned about supply chain management practices in Chennai's automotive industry, revealing a number of insights that have very real implications for theory and practice. In the dimension of responsiveness and flexibility, electric vehicle (EV) producers demonstrate much better performance, leading to the conclusion that newer entrants to the automotive industry in comparison to established manufacturers are pursuing and adopting more agile supply chain practices. The finding is consistent with theorizing of industry evolution in addition to late mover advantages of adopting best practices.

The positive association between adopting technology and performance in the supply chain supports theoretical arguments on the benefits of digital transformation for manufacturers' supply chains. The low adoption of advanced technologies, such as artificial intelligence, block chain, and digital twins, suggests that Chennai's automotive industry is still in the early stages of digital transformation. While this poses an obstacle to competitiveness, it offers an opportunity to gain competitive differentiation and performance.

The investigation into supplier relationships uncovering a structured, natural hierarchy suggests that OEMs have higher quality strategic alliances than lower-tiers, corroborates transaction cost theory and resource-based view and implies that firms who have larger buyer power and need for suppliers resources have more to spend on supplier relationship. Additionally, the regression analysis that identified technology adoption, supplier relationship quality, and organizational capabilities as drivers of performance in the supply chain performance together provide empirical validation for the use of theoretical perspectives with respect to the multidimensional aspects of supply chain competence. In addition, the negative effect of market uncertainty on performance emphasises the need for supply chain resilience and risk management capabilities in unstable market situations.

The issue of infrastructure quality as an important performance driver is interesting and reflective of the context of emerging market manufacturing settings. For policy makers and authorities interested in promoting industrial development in their jurisdictions, the finding about related infrastructure provides evidence that investments in infrastructure can enable supply chain competitiveness and contributes to overall industrial performance.

Implications and Recommendations

The research results present important implications for a variety of stakeholders including manufacturers, technology providers, policy makers, and academic researchers. For the automotive sector manufacturers in Chennai, implications are that there are a variety of performance outcomes associated with the potential for investment in technology adoption and supplier relationship development. Manufacturing companies should begin to adopt existing technology, like ERP systems and supplier portals, and begin to develop competency in new technology.

The better performance of electric vehicle manufacturers suggests that traditional automotive manufacturers must redesign their supply chains in order to compete in the new landscape of the industry. This may involve reconstructing the supplier network, investing in new technological capabilities, and developing organisational competencies that support emerging mobility spaces.

The implications for policy makers and industrial development authorities indicate that related to infrastructure development, infrastructural development is an important element of reducing supply chain costs, which supports competitiveness. Therefore, investments in transportation networks, such as digitally enabled infrastructure networks, logistics facilities, etc. can simplify value creation for the entire automotive ecosystem. Further, policies that enhance technology adoption and skill development, can improve the competitive positioning of the industry.

Technology providers and developers of solutions can take advantage of the huge market opportunity represented by the low levels of adoption for advanced technologies in the automotive industry in Chennai. However, to effectively break into the market, they will need to provide solutions that are designed to meet the needs and limitations of an emerging market manufacturer. Their needs include cost, complexity of implementation, and integration.

Research also indicates that educational institutions and training providers need to focus on developing competencies in supply chain management that encompasses technology capabilities and relationship management competencies. The evolution in the industry is resulting in a workforce that understands not only traditional manufacturing issues, but can also operationalize emerging technologies.

Limitations and Future Research

Although a comprehensive study, this research has some limitations which need to be acknowledged this can be considered in future research. First, although the nature of the study was cross-sectional, the findings provide an insight into the supply chain practices at a specific point in time rather than reflecting the ongoing changes that affect supply chain capabilities and performance. Longitudinal studies would be more beneficial in revealing the manner in which supply chain practices are evolving based on changes presented by the industry and associated technologies. Second, the concentration on Chennai offered depth, however, was limiting in terms of drawing comparisons with other automotive manufacturing regions in India and other emerging markets. More comparative studies on a number of automotive clusters would have additional value in appreciating best practices and differences between clusters. The focus of this study was suppliers and there is the potential to add value to future research by exploring the customer side and supply chain relationship dynamics in understanding not only the supplier perspective but from the customer and demand side. As discussed above, supply chain performance was relying on perceptions as reported by managers and understandably scepticism of using perceptual measures to assess the actual performance of a supply chain readymade the study limited. Possible future research could involved a combination of internal financial performance data and operational metrics, and external assessment(s) of customer and third party stakeholder performance in order to take a more comprehensive approach to performance measurement. Finally, considering the speed of technological change, the technical practices described in this study may be out dated in a very short amount of time. An ongoing exploration of the use of these technologies and their influence on supply chain performance would add value for practitioners and academics alike. Future research opportunities include examining the influence of sustainability initiatives on supply chain performance and how regulations and government policies affect supply chain activities; additionally, future research could examine the differences in domestic and export-oriented manufacturers' supply chain strategies in the Chennai automotive sector.

CONCLUSION

This empirical study of supply chain management in Chennai's automobile sector provides full details of current practices, performance metrics, and success factors in one of India's major manufacturing centres. The research shows that supply chain performance varies significantly by automotive sector, with electric vehicle manufacturers exhibiting more agility and responsiveness overall than traditional automotive manufacturers. The research identifies technology adoption and supplier relationship quality as the main antecedents of supply chain performance while underlining the continuing significance of quality of infrastructure and organizational capabilities. The fairly low rates of adoption of advanced technology point to a considerable potential for performance levels to improve through leveraging technology development initiatives known commonly as a digital transformation process. The study adds to the supply chain management literature in each of the ways articulated above by including empirical case evidence from an emerging market and by demonstrating the applicability of universal supply chain theories in a geographically unique automotive cluster, the situation of which is Chennai. The research has also presented a number of pragmatic insights to industry practitioners on strategic priorities for supply chain development and performance improvement. The outperformance of electric vehicle manufacturers indicates that the automotive industry transformation offers the potential for supply chain innovation and competitive advantages. Traditional automotive companies should rethink their supply chain strategy in order to remain competitive, while new entrants will benefit from adopting agile frameworks and broker smart technologies to enter the business. As the automotive industry in Chennai evolves in order to meet the global automotive market's competitive positioning, continued commitment to the adaptation of technology, development of the supply base, and improving infrastructure is essential. For these proposals to consider as strategic initiatives this research has offered some options and has also provided some ways to assess the journey in supply chain development. The test analysis this research has presented supports the argument for that competitive advantage lies in effective supply chain management in the automotive industry. Given the automotive industry undergoes continual change influenced by technological disruptions and changing customer expectations, supply chain capabilities will be an even more important consideration in the future success in the global automotive marketplace.

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