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Barriers to Workforce Strategy Development in the Automotive Industry: An Empirical Analysis of the Indian Passenger Vehicle Sector Using ISM and MICMAC

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Abstract

The automotive industry in India is undergoing a rapid digital transformation, necessitating a skilled workforce proficient in emerging technologies. However, multiple barriers impede the effective adoption of such a workforce. This study aims to analyze the interrelationships and hierarchical structure of these barriers within the Indian passenger vehicle sector. Data were collected through semi-structured interviews conducted between April 2024 and July 2025 with senior professionals from leading automotive companies and academicians with established publications in the field (ABDC A- or B-ranked journals). Of the 40 potential respondents approached via email and LinkedIn, 10 provided written consent and participated in the interviews. The responses were transcribed and subjected to thematic analysis, which identified ten key barriers influencing skilled workforce adoption in the era of automotive digital transformation. Interpretive Structural Modeling (ISM) was used to establish the hierarchical structure of these barriers, while MICMAC (Matrice d'Impacts Croisés-Multiplication Appliquée à un Classement) analysis was employed to classify them according to their driving and dependence power. The root causes appear to include poor training infrastructure, shortcomings in industry-academia collaboration, and policy inefficiencies. These root causes strongly influence other dependent barriers, such as the limited availability of digital skill sets, the high cost of upskilling, and low workforce adaptability due to organizational resistance to change. This structured understanding provides strategic insights for policymakers, industry leaders, and educators seeking to design targeted interventions to strengthen the digital workforce ecosystem in India's passenger vehicle sector.

Keywords: skilled workforce barriers, Interpretive Structural Modeling (ISM), MICMAC analysis, India, semi-structured interviews, industry-academia collaboration

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汽车工业劳动力战略制定的障碍：基于ISM和MICMAC的印度乘用车行业实证分析

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摘要

当前，印度汽车产业正经历快速的数字化转型，行业亟需具备新技术应用能力的高素质人才。然而，在现阶段，人才队伍建设面临一系列障碍，制约了相关人才储备体系的有效构建。本文以印度乘用车制造业为例，分析这些障碍之间的相互关系及其层级结构。研究数据来源于2024年4月至2025年7月开展的半结构化访谈。受访者包括印度领先汽车企业的高层管理人员，以及在商业、管理与经济学领域权威国际期刊上发表过相关成果的学术界人士。研究团队通过电子邮件和LinkedIn联系了40位潜在受访者，其中10位以书面形式同意参加访谈。访谈资料经转录后，采用主题分析法加以处理，识别出影响汽车工业数字化转型背景下人才队伍建设的10项基础性障碍。在此基础上，运用ISM（解释结构模型）确定了这些障碍的层级结构，并借助MICMAC分析，根据其依赖性和驱动力对其进行了分类。研究发现，基础性障碍主要包括教育基础设施薄弱、产学互动不足以及政府政策效能不足。此外，研究还识别出若干在很大程度上受上述基础性障碍影响的次级障碍，包括具备必要数字化能力的人才短缺、技能提升项目成本过高、员工变革准备不足以及组织层面对转型的抵制等。上述结构化研究结果为政府部门、行业管理者和教育界提供了重要参考，有助于制定更具针对性的政策与措施，从而完善支撑印度乘用车制造业数字化转型的人才培养体系。

关键词：解释结构模型（ISM）、MICMAC分析、印度、半结构化访谈、产学互动

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Introduction

The passenger vehicle sector in India is undergoing an unprecedented digital transformation driven by the rapid adoption of Industry 4.0 technologies, including automation, artificial intelligence (AI), the Internet of Things (IoT), robotics, and data analytics [Singh, Kaur, 2025]. The sector's evolution from traditional assembly lines to integrated manufacturing ecosystems reflects a global trend toward intelligent production, enhanced product design, predictive customer service, and supply chain optimization [Ojha et al., 2024; Singh, Kaur, 2025]. These changes are not merely technological; they signal a fundamental shift in how automotive companies create value and adapt to changing market demands, environmental imperatives, and consumer preferences. The Indian government's Digital India, Make in India, FAME, and Skill India programs have played instrumental roles in enabling this transformation by fostering digital infrastructure upgrades, incentivizing R&D, and encouraging industry-academia collaboration [Human Resource.., 2019; Ojha et al., 2024; Singh, Kaur, 2025].

Despite the sector's dynamic progress, Indian automotive manufacturers face significant barriers in cultivating a workforce suited to the digital era. Modern vehicle production increasingly demands data scientists, cybersecurity experts, robotic technicians, and AI specialists, yet the industry continues to experience persistent shortages of such talent [Human Resource.., 2019; Ojha et al., 2024]. The lack of specialized training infrastructure, outdated curricula in technical institutions, and limited industry-academia collaboration are major obstacles restricting the supply of skilled professionals [Human Resource.., 2019; Singh, Kaur, 2025]. These impediments are further aggravated by organizational resistance to change, the high costs of implementing digital transformation, and the need for robust IT infrastructure capable of integrating advanced technologies with legacy systems [Ojha et al., 2024; Singh, Kaur, 2025]. Small and medium-sized enterprises (SMEs) are particularly vulnerable, as limited funding and human capital make technology adoption especially challenging [Rawat et al., 2021; Ojha et al., 2024; Sharma, Paliwal, 2026].

Digital transformation has also introduced new forms of interconnectedness and complexity, especially with the advent of connected vehicles, telematics, electric mobility platforms, and cloud-based analytics [Singh, Kaur, 2025]. Case studies of leading Indian automakers such as Tata Motors and Mahindra & Mahindra demonstrate significant investments in IoT sensors, AI-driven robotics, remote diagnostics, and predictive maintenance [Singh, Kaur, 2025]. Tata Motors, for example, has implemented the iRA platform for real-time vehicle analytics and remote management, while Mahindra has developed its NEMO platform to provide seamless digital experiences for users and fleet managers [Singh, Kaur, 2025]. Maruti Suzuki and Hero MotoCorp are similarly expanding digital platforms across product development, manufacturing, and customer support, signaling a sector-wide embrace of digital integration. However, the full benefits of these initiatives cannot be realized without a skilled and adaptive workforce capable of designing, deploying, and maintaining complex digital systems [Ojha et al., 2024; Singh, Kaur, 2025].

Barriers to skilled workforce adoption in the context of automotive digital transformation are multifaceted and deeply interconnected. High implementation costs, inadequate IT infrastructure, resistance to organizational change, insufficient legislation, data privacy concerns, and cybersecurity risks have emerged as critical challenges limiting workforce transformation [Rawat et al., 2021; Ojha et al., 2024]. For instance, advanced manufacturing facilities in urban centers have access to technologies such as automated guided vehicles (AGVs), digital twins, and real-time data analytics, yet comparable progress remains uneven in tier-2 and tier-3 cities, where basic digital infrastructure is still underdeveloped [Singh, Kaur, 2025]. Workforce readiness is further hampered by skill deficiencies: while Industry 4.0 demands expertise in data analytics, robotics, cloud platforms, and AI, many engineering and vocational programs lag behind in updating their curricula [Human Resource.., 2019; Singh, Kaur, 2025]. As a result, a persistent gap remains between industry needs and the skills imparted by traditional institutions, necessitating robust re-skilling and upskilling initiatives for the current workforce [Human Resource.., 2019; Singh, Kaur, 2025].

Organizational resistance to change is another formidable barrier. Established companies with decades-old practices and legacy systems often struggle with interoperability between conventional and modern digital solutions [Ojha et al., 2024]. Employee skepticism and reluctance to adopt new tools are common and can lead to inefficiencies or failed technology rollouts. This resistance is frequently exacerbated by the lack of involvement of middle and lower management in digital change processes. Successful implementation depends on coordinated efforts across multiple organizational levels, requiring leadership buy-in, inclusive decision-making, and robust change management strategies [Kamble et al., 2018a; Ojha et al., 2024].

Cybersecurity has come to the forefront as digital ecosystems expose vehicles, plants, and data repositories to unprecedented threats. Connected vehicles and digitally managed production lines are increasingly vulnerable to hacking, creating risks to operational integrity, customer privacy, and intellectual property [Ojha et al., 2024; Singh, Kaur, 2025]. Many Indian companies lack dedicated cybersecurity teams capable of mitigating risks, and industry-wide data protection standards are still evolving. Government initiatives encourage standardization and the strengthening of digital safety protocols, but widespread adoption remains a work in progress [Singh, Kaur, 2025].

Another layer of complexity arises from the integration of advanced data analytics and AI into vehicle production, quality assessment, logistics, and in-vehicle experiences [Ojha et al., 2024]. While digital platforms now enable real-time decision-making, predictive analytics, and product personalization, the ability to leverage these technologies is fundamentally constrained by workforce capability. The shortage of data analysts, AI experts, and digital strategists prevents companies from fully capitalizing on the potential of digital transformation [Ojha et al., 2024; Singh, Kaur, 2025].

Interpretive Structural Modeling (ISM) and MICMAC analysis have gained prominence in academic and applied research as robust methodologies for systematically investigating the structure and interrelations of barriers to workforce adoption in digital transformation [Kamble et al., 2018b; Luthra, Mangla, 2018; Ojha et al., 2024]. The ISM process enables experts to identify, rank, and map barriers according to their driving and dependent powers, ultimately yielding a hierarchy that reveals root causes and influential linkages [Ojha et al., 2024]. MICMAC analysis further categorizes these barriers into autonomous, dependent, linkage, and driving clusters, reflecting their influence within the transformation landscape. Empirical studies have shown that barriers such as geopolitical risk, lack of robust IT infrastructure, and integration challenges serve as driving forces, whereas issues like competitive pricing pressure and the risk of obsolescence tend to function as dependent variables within the ISM framework [Kamble et al., 2018a; Ojha et al., 2024].

In recent large-scale surveys, such as those employed by [Ojha et al., 2024], barriers were quantitatively ranked using Likert-scale responses, with expert validation from both academia and industry practitioners. The studies found that “integration of technology,” “cyberattacks,” and “high cost of implementation” consistently emerged as top-ranked challenges, particularly for SMEs. Expert interviews and questionnaire analyses revealed that robust IT infrastructure and geopolitical risks underpin the ecosystem’s overall capacity for digital transformation [Ojha et al., 2024]. The ISM model presented in these studies places drivers such as geopolitical risk at the base, where they influence numerous higher-level barriers within the ecosystem [Ojha et al., 2024]. These findings align with thematic observations from the Indian context, where digital transformation is hindered by gaps in infrastructure, investment, skilled talent, and cross-functional integration [Human Resource.., 2019; Singh, Kaur, 2025].

The inherent complexity of the Indian automotive workforce ecosystem demands holistic interventions. Strategic alliances between industry leaders and academic institutions are pivotal in bridging skill gaps, updating curricula, and preparing the workforce comprehensively for future demands [Human Resource.., 2019; Singh, Kaur, 2025]. Public-private partnerships in R&D, skills development, and digital infrastructure are integral to sustainable progress. Incremental adoption of modular or scalable technologies may reduce cost barriers, especially for smaller enterprises [Singh, Kaur, 2025].

This research emerges from the context of these multifaceted challenges and opportunities. By engaging practitioners and academicians through targeted semi-structured interviews, this study seeks to illuminate the core variables affecting skilled workforce adoption in the era of automotive digital transformation. Through the lens of ISM and MICMAC, the study aims to map the critical barriers, their hierarchical interrelationships, and their strategic significance for India’s automotive sector. The findings are intended to inform not only industry stakeholders but also policymakers and educators of actionable pathways for workforce development and ecosystem enhancement.

The convergence of digital transformation and workforce dynamics in India's passenger vehicle sector is ultimately a story of adaptation, resilience, and innovation. As the sector navigates the complexities of automation, AI, connected ecosystems, and electric mobility, the challenge lies in equipping the workforce with the skills and agility required to drive the next phase of growth. Achieving this adaptation calls for a concerted effort to dismantle entrenched barriers, foster collaboration, and implement systemic change driven by evidence-based strategies. With sound leadership, forward-thinking policies, and expert-guided strategic models such as ISM and MICMAC, India's automotive sector can harness the vast opportunities of digital transformation while overcoming the persistent barriers to skilled workforce adoption [Ojha et al., 2024; Singh, Kaur, 2025].

1. Literature Review

The digital transformation of the Indian passenger vehicle sector is progressing rapidly, driven by emerging technologies woven into the fabric of Industry 4.0, encompassing artificial intelligence (AI), the Internet of Things (IoT), robotics, cloud computing, and advanced data analytics [Ojha et al., 2024; Singh, Kaur, 2025]. This transformation is altering manufacturing processes, product design, and business models, offering substantial competitive advantages. Yet, the full realization of these benefits depends on the availability and effective adoption of a skilled workforce proficient in these complex digital competencies [Human Resource.., 2019; Singh, Kaur, 2025]. The literature vividly illustrates a persistent and multifaceted set of barriers constraining the adoption of such a workforce, especially within India's passenger vehicle sector, which remains at an inflection point, balancing traditional manufacturing legacies with disruptive digital demands [Kamble et al., 2018b; Ojha et al., 2024].

1.1. Digital Transformation and Workforce Challenges in the Indian Automotive Sector

Recent studies underscore that digital transformation is more than the introduction of technology; it represents a paradigm shift requiring workforce realignment, continuous skill enhancement, and organizational cultural change. [Ojha et al., 2024] highlights the complexity of implementing Industry 4.0, wherein workforce skills not only support but also drive digital innovations, including automation, predictive analytics, and connected vehicle technologies. Similarly, [Singh, Kaur, 2025] emphasize India's governmental policy framework, such as Digital India and Skill India, which aims to synchronize workforce competencies with industry needs but faces challenges in execution and reach, particularly in semi-urban and rural manufacturing hubs lacking digital infrastructure.

Literature across the past decade points to three dominant workforce-focused barriers: skill deficits, inadequate training infrastructure, and organizational resistance to digital adoption [Kamble et al., 2018a; Ojha et al., 2024]. Skill deficiencies span core digital skills such as data analytics, cybersecurity, AI, and machine learning, as well as soft skills related to adaptability and change management [Human Resource.., 2019; Singh, Kaur, 2025]. Many technical education institutes continue to rely on curricula that lag behind fast-evolving industry requirements, perpetuating a gap between fresh graduates' capabilities and market expectations [Ojha et al., 2024]. Workforce upskilling and reskilling emerge as critical intervening forces, although current efforts remain fragmented and insufficient in scale [Singh, Kaur, 2025].

Organizational resistance, often caused by entrenched legacy systems and hierarchical corporate cultures, limits adoption momentum within automotive companies [Kamble et al., 2018a; Ojha et al., 2024]. Resistance is not only evident at the operational level but also among middle and senior managers, where fear of redundancy, unfamiliarity with digital processes, and inertia may prevail [Ojha et al., 2024]. Literature documents that overcoming such resistance requires top management support, transparent change management strategies, and inclusive communication that involves workers at all levels [Kamble et al., 2018b].

Furthermore, SMEs face unique challenges due to limited financial resources, the smaller scale of training initiatives, and uneven access to cutting-edge technology [Ojha et al., 2024]. Government subsidies and incentives, while present, tend to be skewed toward larger OEMs, creating disparities in workforce digital readiness between tier-1 manufacturers and their smaller suppliers or contractors [Singh, Kaur, 2025].

Other notable barriers discussed in the literature include cybersecurity risks associated with interconnected manufacturing environments, the lack of standardized protocols for technology integration, and policy-level ambiguities around data protection and digital labor laws [Ojha et al., 2024; Singh, Kaur, 2025]. These infrastructural and regulatory gaps exacerbate workforce uncertainties, reducing motivation to adopt new skills or invest heavily in digital transformation efforts [Ojha et al., 2024].

1.2. Methodologies in Literature to Analyze Workforce Adoption Barriers

Among the analytical techniques used to understand these barriers, Interpretive Structural Modeling (ISM) and MICMAC (Matrice d'Impacts Croisés-Multiplication Appliquée à un Classement) analysis feature prominently in recent automotive Industry 4.0 research [Kamble et al., 2018b; Ojha et al., 2024]. ISM offers a structured method to decompose complex interrelated factors into a hierarchical model that clarifies root causes, intermediate catalysts, and dependent outcomes [Ojha et al., 2024]. MICMAC complements this by classifying barriers into autonomous, linkage, dependent, and driving clusters according to their driving and dependence power, offering stakeholders a clear roadmap for prioritizing interventions [Kamble et al., 2018b].

Literature applies ISM and MICMAC extensively in scenarios characterized by technological complexity and organizational interdependence, such as smart manufacturing ecosystems and digital supply chains [Kamble et al., 2018a; Ojha et al., 2024]. These techniques facilitate consensus-building among experts from industry and academia, revealing the multi-layered nature of barriers that might otherwise appear isolated or unrelated [Ojha et al., 2024]. For the Indian automotive sector, these models enable a nuanced visualization of how factors such as infrastructure deficits, workforce competencies, organizational culture, and policy frameworks dynamically influence one another.

1.3. Research Objectives

Building on these substantial insights, this research aims to advance understanding specifically within the Indian passenger vehicle sector, where skill adoption barriers pose a strategic bottleneck for sustained digital transformation. The objectives of this study are as follows:

1. To identify and validate the critical barriers impacting skilled workforce adoption in the era of automotive digital transformation within the Indian passenger vehicle industry.
2. To analyze the interrelationships and hierarchical structure of these barriers utilizing Interpretive Structural Modeling (ISM).
3. To classify and map the driving and dependence power of the barriers through MICMAC analysis.
4. To provide strategic recommendations for policymakers, industry leaders, and educators aimed at overcoming these barriers and accelerating workforce digital readiness.

1.4. Top Ten Variables Impacting Skilled Workforce Adoption

Based on a comprehensive literature survey and expert interviews, the top ten variables impacting skilled workforce adoption in automotive digital transformation are as follows:

- Inadequate training and skill development infrastructure

The lack of modern training centers, industry-relevant curriculum, and continuous professional development programs hampers workforce readiness [Human Resource.., 2019; Singh, Kaur, 2025].

- Organizational resistance to change

Cultural inertia and apprehension among employees and middle management obstruct the uptake of new digital processes and technologies [Kamble et al., 2018a; Ojha et al., 2024].

- Lack of industry-academia collaboration

Weak linkages between automotive firms and educational institutions result in misaligned skill development efforts and limited practical training opportunities [Ojha et al., 2024; Singh, Kaur, 2025].

- Insufficient digital literacy among existing workforces

Many current employees have inadequate exposure to digital tools and concepts, limiting their ability to adapt to Industry 4.0 environments [Human Resource.., 2019; Singh, Kaur, 2025].

- High implementation costs of digital technologies

The significant capital investment required for automation, IoT, and AI tools deters many firms, especially SMEs, from committing fully to digital workforce enablement [Ojha et al., 2024].

- Inadequate IT infrastructure and connectivity

Especially in tier-2 and tier-3 cities, poor internet connectivity and outdated digital infrastructure limit the scope of digital transformation [Ojha et al., 2024; Singh, Kaur, 2025].

- Cybersecurity concerns and data privacy

Growing cyber threats and unclear regulatory guidelines contribute to workforce hesitation and cautious adoption of digital technologies [Ojha et al., 2024; Singh, Kaur, 2025].

- Policy and regulatory uncertainties

Ambiguities in digital labor laws, data governance, and the lack of concrete government incentives hinder strategic planning for workforce transformation [Singh, Kaur, 2025].

- Limited awareness and understanding of digital transformation benefits

Both managers and employees often lack comprehensive knowledge about the potential advantages, contributing to hesitancy and resistance [Kamble et al., 2018a].

- Workforce adaptability and change management deficits

The ability to manage change effectively at all organizational levels remains limited due to insufficient leadership focus and training [Ojha et al., 2024].

1.5. Implications from Literature

The literature consistently suggests that these barriers do not exist in isolation but form a dense network of cause-and-effect relationships that must be understood holistically [Kamble et al., 2018a; Ojha et al., 2024]. For example, inadequate training infrastructure is a primary driver that exacerbates digital literacy gaps and workforce adaptability issues. Similarly, organizational resistance often stems from limited awareness and poor change management, which can be mitigated through stronger industry-academia partnerships and government incentives [Singh, Kaur, 2025]. Studies recommend that addressing these variables through targeted policies, strategic industry collaboration, and investment in scalable training solutions will prove vital to accelerating India's automotive digital transformation and workforce development [Ojha et al., 2024; Singh, Kaur, 2025]. The deployment of ISM and MICMAC analyses offers a pragmatic pathway for stakeholders to prioritize interventions and optimize resource allocation effectively.

2. Research Methodology

The research methodology for this study is structured around qualitative inquiry, employing semi-structured interviews in combination with Interpretive Structural Modeling (ISM) and MICMAC analysis to explore the interrelationships and hierarchical structure of barriers to skilled workforce adoption within the Indian passenger vehicle sector's digital transformation initiatives. This multi-step methodology is grounded in emerging best practices discussed in recent literature on automotive industry transformation and workforce agility [Debnath et al., 2023; Ruben et al., 2023; Ojha et al., 2024].

To comprehensively map the barriers and their interconnections, data collection was initiated via purposive sampling, targeting expert practitioners and academicians directly involved in or published on automotive digital transformation, with established publications in the field (ABDC A- or B-ranked journals). Potential respondents from leading automotive companies and academia were contacted via email and LinkedIn, with participation based on explicit written consent to ensure ethical compliance and confidentiality [Bajpai, 2019; Singh, Kaur, 2025]. The study ultimately involved 10 expert participants out of the 40 approached, ensuring that the sample consisted of highly relevant stakeholders.

Semi-structured interviews were deployed as the primary qualitative data collection method. This technique offers a balance between guided inquiry and flexibility, allowing experts to elaborate on contextual and hidden dimensions of workforce barriers while ensuring systematic comparability across interviews [Bajpai, 2019; Horváth, Szabó, 2019; Ruslin, 2022]. Interviews were conducted from April 2024 to July 2025, each lasting approximately 60–90 minutes, and they were transcribed verbatim for detailed analysis. The use of semi-structured interviews aligns with contemporary qualitative research on industry change, where in-depth expert insights are crucial for capturing the dynamic interplay of technological, organizational, and policy-driven barriers [Bajpai, 2019; Horváth, Szabó, 2019; Singh, Kaur, 2025].

Once collected, the interview data were subjected to thematic analysis, which identified recurrent themes and distinct variables impacting skilled workforce adoption. Thematic coding was executed by two independent researchers to maximize validity and minimize bias, with disagreements resolved through consensus. From dozens of interview-derived statements, ten core variables were identified as primary barriers. These include inadequate training infrastructure, organizational resistance to change, limited industry-academia collaboration, insufficient digital literacy, high implementation costs, inadequate IT infrastructure, cybersecurity and data privacy concerns, policy/regulatory uncertainties, limited awareness of the benefits of digital transformation, and deficits in change management and adaptability.

Following qualitative coding, the ISM methodology was applied, adhering to the approach established by [Warfield, 1973] and adapted for the automotive context by recent scholars [Ojha et al., 2024; Debnath et al., 2023]. ISM supports the development of a hierarchical model illustrating how each barrier influences others within a structured matrix. First, a Structural Self-Interaction Matrix (SSIM) was developed from the expert sample, with pairs of variables systematically compared to establish directional relationships based on consensus judgments. The SSIM was subsequently used to construct initial and final reachability matrices, mathematically determining which barriers drive others and which are more dependent within the overall system [Ruben et al., 2023; Ojha et al., 2024].

Upon completion of the ISM phase, the established hierarchical order was subjected to MICMAC analysis, as introduced by [Faisal et al., 2009] and widely adopted in digital workforce studies within the manufacturing and automotive sectors [Debnath et al., 2023; Ojha et al., 2024]. MICMAC analysis groups the identified barriers according to their driving and dependence powers, classifying them into autonomous, dependent, linkage, and driving clusters for enhanced strategic clarity. Barrier variables with high driving power and low dependence, such as training infrastructure and IT investment deficits, were prioritized as strategic bottlenecks for intervention, while highly dependent variables, such as adaptability and awareness, were deemed outcomes that improve as driving barriers are addressed [Ruben et al., 2023; Ojha et al., 2024].

This mixed-method approach thus enables a comprehensive mapping of the barriers to skilled workforce adoption, linking qualitative depth and expertise with robust quantitative modeling. The integration of thematic coding, ISM, and MICMAC represents the methodological frontier in Industry 4.0 and automotive workforce research, providing both diagnostic insights and practical strategies for policymakers, educators, and industry leaders [Bajpai, 2019; Debnath et al., 2023; Ojha et al., 2024].

Ethical compliance was strictly maintained throughout the study. Participant data were anonymized and stored securely. Only experts with written informed consent were included, and the study protocol was reviewed for alignment with institutional ethical standards.

3. Research Analysis and Findings

This section presents the systematic analysis of the data collected from expert interviews. It details the application of Interpretive Structural Modeling (ISM) and MICMAC analysis to identify, structure, and classify the ten critical barriers to skilled workforce adoption within the Indian passenger vehicle sector.

The thematic analysis of expert interview transcripts yielded ten key barriers. For ease of analysis in the ISM and MICMAC processes, these barriers are assigned codes (B1 to B10), as shown in Table 1.

Table 1
Key Barriers to Skilled Workforce Adoption

Code	Barrier Description
B1	Inadequate training and skill development infrastructure
B2	Organizational resistance to change
B3	Lack of industry-academia collaboration
B4	Insufficient digital literacy among the existing workforce
B5	High implementation costs of digital technologies
B6	Inadequate IT infrastructure and connectivity
B7	Cybersecurity concerns and data privacy
B8	Policy and regulatory uncertainties
B9	Limited awareness of digital transformation benefits
B10	Workforce adaptability and change management deficits

Source: prepared by the authors.

The contextual relationships between the barriers were established based on expert opinions. The four symbols used to denote the direction of the relationship for each barrier pair (i, j) are:

– V: Barrier i leads to Barrier j;
– A: Barrier j leads to Barrier i;
– X: Barriers i and j lead to each other (mutual influence);
– O: No perceived relationship between the barriers.

The resulting SSIM is presented in Table 2.

In Table 2, the cell (B1, B2) has a 'V', meaning that experts agreed that inadequate training infrastructure (B1) leads to organizational resistance to change (B2).

The SSIM was converted into a binary initial reachability matrix using the following rules: V = 1, A = 1, X = 1, and O = 0. The transitivity of the contextual relations was then incorporated (i.e., if A leads to B and B leads to C, then A leads to C) to develop the final reachability matrix, shown in Table 3. The driving power and dependence of each barrier were calculated as the row sum and column sum, respectively.

The barriers were partitioned into different levels based on their reachability and antecedent sets. This iterative process helps determine the hierarchy, with the top level representing the least driving (most dependent) barriers.

Final level partition:

– Level I: Workforce Adaptability and Change Management Deficits (B10);
– Level II: Limited Awareness of Benefits (B9), Insufficient Digital Literacy (B4), High Implementation Costs (B5), and Cybersecurity Concerns (B7);
– Level III: Organizational Resistance to Change (B2);
– Level IV: Inadequate IT Infrastructure (B6) and Policy Uncertainties (B8);
– Level V: Lack of Industry-Academia Collaboration (B3);
– Level VI: Inadequate Training Infrastructure (B1).

Interpretive Structural Modeling (ISM) was used to determine the hierarchical relationships among the ten barriers to skilled workforce adoption in the digital transformation of India's

Table 2
Structural Self-Interaction Matrix (SSIM)

Barrier	B10	B9	B8	B7	B6	B5	B4	B3	B2
B1	V	V	V	V	V	V	V	V	V
B2	V	V	A	A	A	A	A	A	–
B3	V	V	V	A	V	V	V	–	–
B4	A	A	A	A	A	A	–	–	–
B5	A	A	A	A	A	–	–	–	–
B6	V	V	V	A	–	–	–	–	–
B7	A	A	A	–	–	–	–	–	–
B8	V	V	–	–	–	–	–	–	–
B9	A	–	–	–	–	–	–	–	–

Source: prepared by the authors.

Table 3
Final Reachability Matrix

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	Driving Power
B1	1	1	1	1	1	1	1	1	1	1	10
B2	0	1	0	0	0	0	0	1	1	1	4
B3	0	1	1	1	1	1	1	1	1	1	9
B4	0	0	0	1	0	0	0	0	0	1	2
B5	0	0	0	0	1	0	0	0	0	1	2
B6	0	1	0	1	1	1	1	1	1	1	8
B7	0	0	0	0	0	0	1	0	0	1	2
B8	0	1	0	1	1	1	1	1	1	1	8
B9	0	0	0	0	0	0	0	0	1	1	2
B10	0	0	0	0	0	0	0	0	0	1	1
Dependence	1	5	2	5	5	4	5	5	6	10	

Source: prepared by the authors.

passenger vehicle sector. Based on expert interviews and matrix development, the ISM hierarchical order is presented in Table 4.

Table 4
Analysis of Barriers to Skilled Workforce Adoption

Level	Barrier	Role
1	Inadequate training infrastructure	Driver
1	Inadequate IT infrastructure and connectivity	Driver
2	Policy and regulatory uncertainties	Linkage
2	High implementation costs	Linkage
3	Lack of industry-academia collaboration	Linkage
3	Organizational resistance to change	Linkage
4	Cybersecurity and data privacy concerns	Linkage
5	Insufficient digital literacy	Dependent
5	Limited awareness of digital transformation benefits	Dependent
5	Workforce adaptability and change management deficits	Dependent

Source: prepared by the authors.

Drivers are foundational barriers, exerting high influence over other variables; linkage barriers interact both upward and downward; dependent barriers are more likely to be effects than causes.

Explanatory notes on ISM levels

- Level 1 (Drivers):

Inadequate training and IT infrastructure are found at the base level, signifying their critical role in influencing all other barriers. Improvements here cascade upward, enabling progress in other areas [Ojha et al., 2024].

- Levels 2–4 (Linkage):

Barriers like policy/regulation, implementation cost, industry-academia collaboration, organizational resistance, and cybersecurity are positioned centrally. Their status as linkage barriers means that actions taken here will impact multiple connected areas. For example, improving policy clarity can reduce implementation costs and incentivize collaboration [Ruben et al., 2023].

- Level 5 (Dependents):

Barriers such as digital literacy gaps, limited awareness, and adaptability are largely outcomes shaped by the preceding levels. When fundamental and linkage barriers are addressed, these dependent barriers tend to improve in tandem [Kamble et al., 2018]

The MICMAC analysis was performed by plotting the driving power and dependence of each barrier from Table 3 on a graph, categorizing them into four clusters.

MICMAC analysis was performed to assess each barrier's driving and dependency power. Below is the summary presented in Table 6.

Driving barriers (bottom row): These serve as system bottlenecks; improving them yields the strongest effect on overall skilled workforce adoption.

Linkage barriers (middle cluster): Critical transit points; any improvement or deterioration here impacts both drivers and dependents.

Dependent barriers (upper cluster): Outcomes reliant on the successful management of drivers and linkages; they are endpoints in the barrier network.

As applied in this study, ISM translates qualitative expert insights into a quantitative hierarchy, enabling the identification of root causes that must be prioritized for effective skilled workforce adoption [Ojha et al., 2024]. MICMAC's classification complements this by indicating which barriers are most likely to respond to targeted interventions and which will improve as foundational barriers are addressed. The analysis highlights that training, IT infrastructure, and regulatory clarity are the most influential levers for ecosystem change, whereas adaptability, awareness, and digital literacy function as outcomes of strategic progress. Systemic innovation, therefore, relies on concentrated action at the base and linkages of the hierarchy, with cascading benefits for dependent variables [Kamble et al., 2018a; Fauzdar, 2022].

4. Discussion of the Findings

The ISM and MICMAC analyses reveal a clear and actionable structure within this complex web of barriers.

Root Cause Barriers (Cluster IV: Independent Drivers): The analysis identifies inadequate training infrastructure (B1) and lack of industry-academia collaboration (B3) as the most powerful fundamental drivers. Experts consistently highlighted that, without modern labs, updated curricula, and strong, practical collaboration between companies and universities, the pipeline of skilled talent cannot be established. These barriers sit at the base of the ISM hierarchy, initiating a chain of effects that propagates through the entire system.

Table 5
MICMAC Clustering of Barriers

Cluster	Driving Power	Dependence	Barriers	Interpretation
I. Autonomous	Low	Low	–	No barriers fall in this cluster, indicating that all are integral to the system
II. Dependent	Low	High	B4, B5, B7, B9, B10	These are outcome barriers. They have weak driving power but are highly dependent on others. They are often the most visible symptoms of the underlying barriers
III. Linkage	High	High	B2, B6, B8	These are unstable, strategic barriers. Any action on them will have a ripple effect on other barriers and feedback on themselves. They require careful management
IV. Independent (Drivers)	High	Low	B1, B3	These are the root-cause barriers. They have high driving power and low dependence, meaning that they influence the entire system but are not themselves influenced by many other barriers. Addressing these is crucial for systemic change

Source: prepared by the authors.

Table 6
MICMAC Barrier Strength Analysis

Barrier	Driving Power	Dependency Power	Cluster
Inadequate training and skill infrastructure	High	Low	Driving
Inadequate IT infrastructure and connectivity	High	Low	Driving
Policy and regulatory uncertainties	High	High	Linkage
High implementation costs	High	High	Linkage
Cybersecurity and data privacy concerns	Medium	High	Linkage
Lack of industry-academia collaboration	Medium	High	Linkage
Organizational resistance to change	Medium	High	Linkage
Insufficient digital literacy	Low	High	Dependent
Limited awareness of benefits	Low	High	Dependent
Workforce adaptability and change management deficits	Low	High	Dependent

Source: prepared by the authors.

Strategic Leverage Points (Cluster III: Linkage Barriers): Inadequate IT infrastructure (B6), policy and regulatory uncertainties (B8), and organizational resistance to change (B2) form a critical strategic cluster. These barriers have high driving and dependence power, acting as crucial intermediaries. For instance, poor IT infrastructure (B6) directly causes high implementation costs (B5) and low digital literacy (B4). Similarly, unclear policies (B8) foster uncertainty, discouraging investment in training (B1) and technology adoption (B5). Addressing these linkage barriers can create positive feedback loops throughout the system.

Outcome Barriers (Cluster II: Dependent Barriers): The top of the ISM hierarchy and the dependent cluster in MICMAC are populated by barriers that are primarily outcomes of the deeper, driving barriers. High implementation costs (B5), insufficient digital literacy (B4), cybersecurity concerns (B7), limited awareness (B9), and, ultimately, workforce adaptability deficits (B10) are the most visible manifestations. The analysis suggests that simply targeting these dependent barriers (e.g., through awareness campaigns) will be ineffective if the root causes and linkage barriers are not simultaneously addressed.

The ISM model provides a strategic roadmap: interventions must be prioritized from the bottom up. Investing in modern training infrastructure (B1) and fostering industry-academia partnerships (B3) will alleviate pressure on IT infrastructure needs (B6) and help clarify policy requirements (B8). This, in turn, will reduce organizational resistance to change (B2), lower the perceived costs and risks, improve digital literacy, and finally lead to a more adaptable and skilled workforce (B10). This structured understanding moves the conversation from treating symptoms to addressing the core causes of the skilled workforce gap in India's digitally transforming automotive sector.

5. Recommendations and Suggestions

The ISM hierarchy and MICMAC analysis provide a clear, evidence-based roadmap for strategic intervention. The findings indicate that tackling the root causes and linkage barriers is paramount to creating a cascading positive effect throughout the entire ecosystem. The following recommendations are structured for key stakeholders: policymakers, industry leaders, and academic institutions.

Strategic recommendations based on ISM/MICMAC findings:

- For policymakers and industry: Launch a national automotive digital skills mission as a public-private partnership (PPP). This mission should be developed in collaboration with OEMs and large suppliers to establish Centers of Excellence (CoEs) for emerging technologies, including AI, IoT, Robotics, and EV technologies, within existing premier engineering institutes and ITIs. The curriculum must be co-designed and regularly updated by a consortium of industry experts to ensure relevance.
- For academia: Implement a mandatory industry immersion policy for faculty in automotive engineering and computer science departments. Encourage and incentivize sabbaticals for professors to work in R&D divisions of automotive companies to bridge the theory-practice gap.
- For policymakers: Develop a phased digital infrastructure upgrade plan for industrial clusters, especially in Tier-2 and Tier-3 cities. Provide tax benefits and subsidies for companies investing in high-speed connectivity and cloud computing infrastructure. In addition, establish a clear and stable digital automotive policy framework that clarifies data privacy, cybersecurity standards, and intellectual property rights for collaborative R&D, thereby reducing policy and regulatory uncertainties (B8).
- For industry leaders: Champion change leadership programs, not just change management. Top management must visibly sponsor digital initiatives and empower mid-level managers to become ambassadors of change. Create cross-functional digital transformation task forces that include shop-floor employees to foster ownership and reduce resistance (B2).
- For industry: Develop modular, scalable digital solutions that offer a lower cost of entry for SMEs, thereby addressing the perception of high implementation costs (B5). Implement continuous digital literacy upskilling programs for the existing workforce, focusing on practical, hands-on training rather than theoretical concepts to address insufficient digital literacy (B4).
- For all stakeholders: Launch a coordinated digital transformation awareness campaign showcasing success sto-

ries from leading Indian automakers. Use case studies to demonstrate tangible ROI, safety improvements, and job enhancement rather than merely job replacement, thereby increasing awareness and reduce fear (B9).

Stakeholder-specific action plans

For policymakers (central and state governments):

- Incentivize collaboration: Offer additional tax deductions for companies that sponsor student projects, offer internships, and collaborate with academia on curriculum design.
- Fund future skills: Expand the scope of the Skill India Mission and the FAME scheme to specifically include subsidies for advanced digital skill certification programs (e.g., in, additive manufacturing, and cybersecurity) for the automotive workforce.
- Build secure infrastructure: Prioritize the development of secure, high-bandwidth digital infrastructure in automotive manufacturing hubs as part of the Smart Cities Mission.

For industry leaders (OEMs, SMEs, Tier-1 suppliers):

- Adopt a phased approach: Instead of undertaking a full-scale transformation, start with pilot projects in one plant or department. Demonstrate quick wins to build confidence and secure wider buy-in, mitigating resistance and perceived risk.
- Invest in internal change agents: Identify and train high-potential employees to become in-house digital champions and trainers. This is often more effective than relying on external consultants and helps build long-term internal capability.
- Develop clear career pathways: Map out new digital job roles and create clear upskilling pathways for existing employees. Show how mechanics can become robotics technicians or data analysts, making the transformation an opportunity for growth rather than a threat.

For academic and training institutions:

- Revitalize curricula: Move from annual curriculum reviews to dynamic, modular curriculum updates that can incorporate new technologies as they emerge. Introduce more project-based learning with real-world problems provided by industry partners.
- Focus on soft skills: Integrate modules on adaptability, critical thinking, problem-solving, and change management into technical programs to prepare graduates for a volatile technological landscape.
- Offer executive education: Create specialized certificate and diploma programs in automotive digital transformation aimed at upskilling current industry professionals, making such programs a key revenue stream and service to the industry.

6. Conclusion and Future Scope

The digital transformation of India's passenger vehicle sector is an inevitable and powerful force. However, its success is intrinsically tied to the readiness of its workforce. This study has moved beyond merely listing challenges by providing a structural model that reveals the root causes of barriers to skilled workforce adoption.

The analysis unequivocally shows that isolated interventions will yield limited results. A synergistic effort, starting with investments in collaborative training infrastructure (B1) and industry-academia partnerships (B3), is essential to build a strong foundation. This must be supported by policies that enable digital infrastructure development (B6) and reduce regulatory ambiguity (B8), while industry leaders actively work to overcome organizational resistance (B2).

By following the hierarchical roadmap presented in this study, stakeholders can strategically allocate resources to the areas where they will have the greatest impact, ensuring that the Indian automotive workforce not only adapts to the digital era but becomes a primary driver of innovation and global competitiveness.

Future Research

Statistical validation: The developed ISM model can be statistically validated using a larger sample and techniques such as Structural Equation Modeling (SEM).

Sector-specific replication: More nuanced barriers can be identified by replicating this research specifically for either the electric vehicle (EV) ecosystem or the auto-component manufacturing sector.

Dynamic modeling: Another valuable extension is the use of System Dynamics (SD), which would help simulate the impact of policy decisions on barrier removal over time.

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