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Designing a Smart Manufacturing Model in Iran's Automotive Industry Using the Internet of Things and Artificial Intelligence: A Grounded Theory Approach

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ABSTRACT

This study was conducted with the aim of designing a qualitative model of smart manufacturing in Iran's automotive industry. This qualitative study was carried out using the grounded theory method based on the systematic approach of Anselm Strauss and Juliet Corbin (2015). Data were collected through in-depth semi-structured interviews with 12 experts, including production managers, information technology specialists, and university faculty members. Sampling was conducted using purposive and theoretical methods with a snowball strategy until theoretical saturation was achieved. Data analysis was performed using MAXQDA 2020 software in three stages: open coding, axial coding, and selective coding. To ensure the quality of the study, the criteria proposed by Yvonna Lincoln and Egon Guba (1985) were employed, and inter-coder reliability was calculated using Cohen's kappa coefficient, which was found to be 0.86. The findings led to the identification of 313 open codes, 176 concepts, and 36 main categories within the paradigm model framework. The core phenomenon (smart manufacturing) consisted of six components: real-time data integration, predictive analytics and maintenance, autonomous robotics, mass customization, supply chain optimization, and product quality enhancement. Causal conditions (5 categories), contextual conditions (6 categories), intervening conditions (7 categories), strategies (6 categories), and consequences (6 categories) were identified. The proposed model provides an integrated and localized framework for managers and policymakers in Iran's automotive industry and can serve as a roadmap for digital transformation in this sector. Successful implementation of this model requires special attention to technological infrastructure, the development of specialized human resources, and the alignment of supportive policies. Quantitative validation of the model using structural equation modeling is recommended for future studies.

Keywords: *Smart manufacturing, Industrial Internet of Things, Artificial Intelligence, Iran's automotive industry, Grounded theory*

1. Introduction

The global automotive industry is currently undergoing a profound transformation driven by the emergence of Industry 4.0 technologies, digitalization, Artificial Intelligence (AI), and the Industrial Internet of Things (IIoT). Traditional manufacturing systems are increasingly being replaced by intelligent, connected, and data-driven production environments capable of enhancing operational efficiency, product quality, flexibility, and sustainability. The integration of AI and IoT technologies has fundamentally altered the nature of industrial production by enabling real-time monitoring, predictive maintenance, autonomous decision-making, and adaptive manufacturing systems (Ghobakhloo, 2020; Liao et al., 2019). In this context, smart manufacturing has emerged as one of the most strategic priorities for automotive companies seeking to remain competitive in rapidly changing global markets.

Industry 4.0 represents the convergence of cyber-physical systems, cloud computing, big data analytics, machine learning, digital twins, and intelligent automation within manufacturing ecosystems (Elnadi, 2023). These technologies allow manufacturers to optimize production processes, reduce operational costs, improve supply chain coordination, and enhance customer-oriented customization capabilities. The automotive industry, due to its complex production networks and high dependence on precision, automation, and supply chain synchronization, has become one of the primary sectors adopting smart manufacturing technologies (Rodic et al., 2021). Contemporary automotive firms increasingly rely on AI-driven analytics and IoT-enabled systems to improve manufacturing agility and respond more effectively to volatile market demands.

Artificial Intelligence plays a pivotal role in intelligent manufacturing systems by enabling machines and production lines to analyze data, identify patterns, predict failures, and make autonomous operational decisions. AI applications in the automotive industry include predictive maintenance, intelligent quality control, autonomous robotics, production scheduling optimization, demand forecasting, and product design enhancement (Gao et al., 2024; Rodic et al., 2021). The integration of machine learning algorithms into manufacturing systems has significantly improved process efficiency and reduced unplanned downtime in production environments. Predictive maintenance models based on AI techniques such as random forest algorithms and neural networks are increasingly being utilized to identify equipment failures before they occur, thereby reducing maintenance costs and production interruptions (Ajithkumar & Babu, 2025). Similarly, AI-based defect detection systems have improved product quality assurance through real-time anomaly detection and automated inspection processes (Morales-Matamoros et al., 2025).

The Industrial Internet of Things has also become a cornerstone of smart manufacturing transformation. IoT technologies facilitate the interconnection of machines, sensors, devices, and production systems through digital communication networks, enabling real-time data collection and operational visibility across manufacturing processes (Soori, 2023). IoT-enabled smart factories can monitor production lines continuously, optimize energy consumption, improve logistics coordination, and support intelligent decision-making processes. In the automotive industry, IoT technologies are extensively applied in predictive maintenance, smart logistics, inventory management, and intelligent production scheduling (Wang et al., 2021). Furthermore, the combination of IoT and AI technologies creates intelligent manufacturing ecosystems capable of self-optimization and adaptive process management (Kodumuru, 2025).

The integration of AI and IoT technologies has also contributed to the emergence of digital twin systems within automotive manufacturing. Digital twins are virtual representations of physical production systems that enable manufacturers to simulate operations, analyze system performance, and predict potential failures in real time (Liu, 2025). These technologies enhance manufacturing flexibility and facilitate data-driven decision-making processes by providing accurate and dynamic operational insights. The implementation of digital twins in automotive production environments has improved equipment utilization, production planning accuracy, and operational resilience.

Another important dimension of smart manufacturing transformation is the increasing emphasis on sustainability and environmental performance. Modern automotive industries face growing pressure to reduce energy consumption, minimize waste generation, and improve environmental responsibility throughout the supply chain. Smart manufacturing technologies support sustainable industrial development by enabling efficient resource utilization, intelligent energy management, and environmentally optimized production systems (Ghobakhloo, 2020). AI-driven supply chain optimization and IoT-based environmental monitoring systems

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contribute to reducing carbon emissions and improving environmental sustainability within automotive manufacturing ecosystems (Tawfeeq Saleh Al-Sammarraie & Fathi, 2025). Consequently, smart manufacturing is not only considered a technological transformation but also a strategic pathway toward sustainable industrial development.

The implementation of Industry 4.0 technologies in the automotive sector has also transformed product development processes and customer engagement strategies. Smart manufacturing environments enable greater flexibility in product customization, agile manufacturing, and accelerated innovation cycles (Falahat, 2023). AI-assisted design systems, digital simulations, and customer data analytics have improved the efficiency of new product development processes and facilitated the creation of personalized automotive products (Kruachottikul, 2023). Automotive manufacturers increasingly employ advanced digital tools to enhance customer experience, improve after-sales services, and respond rapidly to changing consumer preferences.

Despite the significant opportunities associated with smart manufacturing, the transition toward Industry 4.0 remains highly challenging, particularly in developing economies. The successful implementation of AI- and IoT-based manufacturing systems requires advanced technological infrastructure, substantial financial investment, organizational readiness, and specialized human resources (Hakim & Syahputra, 2023). Several studies have identified organizational resistance, cybersecurity concerns, technological complexity, insufficient digital infrastructure, and lack of skilled personnel as major barriers to Industry 4.0 adoption (Moghaddasi et al., 2020). The implementation of intelligent manufacturing systems also requires effective integration across production, logistics, information systems, and supply chain networks, which increases the complexity of digital transformation initiatives.

In the context of the automotive industry, the successful deployment of smart factories depends on several critical success factors, including leadership commitment, strategic planning, technological readiness, employee competencies, and inter-organizational collaboration (Rezaei & Farahani, 2023). IoT implementation in automotive companies particularly requires secure communication infrastructure, data interoperability, operational integration, and continuous technical support (Hakim & Syahputra, 2023). Furthermore, the dynamic and interconnected nature of smart manufacturing systems demands organizational flexibility and adaptive management capabilities capable of responding to rapid technological changes.

The Iranian automotive industry represents one of the most important industrial sectors in the national economy and plays a substantial role in employment generation, technological development, and industrial production. However, the industry currently faces numerous structural, technological, and managerial challenges that limit its global competitiveness. Traditional production systems, outdated manufacturing technologies, fragmented supply chains, and limited digital integration have reduced the industry's ability to compete effectively in global markets. In recent years, Iranian automotive firms have increasingly recognized the strategic importance of digital transformation and smart manufacturing technologies as mechanisms for improving operational efficiency and industrial resilience (Mozafari Mehr & Taghavifard, 2024).

Nevertheless, the implementation of Industry 4.0 technologies in Iran’s automotive industry remains relatively limited and faces multiple barriers. Financial constraints, economic instability, international sanctions, limited access to advanced technologies, insufficient infrastructure, and shortage of specialized human resources have slowed the digital transformation process within manufacturing organizations (Moghaddasi et al., 2020). Moreover, organizational resistance to change and inadequate policy support mechanisms continue to hinder the adoption of AI- and IoT-based production systems. The complexity of integrating smart manufacturing technologies into existing industrial structures further intensifies these challenges.

Previous studies conducted in Iran have mainly focused on identifying implementation barriers, technological requirements, or critical success factors associated with Industry 4.0 adoption. For example, qualitative research on IIoT implementation in automotive supply chains highlighted the importance of technological readiness, organizational capabilities, and managerial support in facilitating digital transformation processes (Jannatrani et al., 2022). Similarly, studies examining smart factory implementation emphasized the significance of strategic alignment, workforce competencies, and innovation culture in achieving successful technological integration (Rezaei & Farahani, 2023). Research on advanced technology selection in Iran’s automotive parts industry also demonstrated the importance of investment prioritization

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and technological evaluation frameworks in supporting industrial modernization (Tohidi et al., 2021).

Although existing studies provide valuable insights into digital transformation challenges and technological requirements, there remains a significant research gap regarding the development of an integrated and context-specific model for smart manufacturing in Iran's automotive industry. Most previous investigations have focused on isolated technological dimensions or operational challenges without examining the complex interactions among organizational, technological, environmental, human, and strategic factors within a comprehensive theoretical framework. Furthermore, limited attention has been given to the simultaneous integration of AI and IoT technologies in the context of Iranian automotive manufacturing systems.

Grounded theory offers a suitable methodological approach for addressing this research gap because it enables the development of theory directly from empirical data and participant experiences. Through systematic qualitative analysis, grounded theory facilitates the identification of causal conditions, contextual factors, intervening conditions, strategic actions, and consequences associated with complex organizational phenomena. Considering the multidimensional and dynamic nature of smart manufacturing transformation, grounded theory can provide a comprehensive understanding of the processes, interactions, and mechanisms shaping digital transformation within the automotive industry.

Given the increasing importance of AI- and IoT-based manufacturing systems, the strategic necessity of digital transformation in Iran's automotive sector, and the lack of an integrated indigenous model for smart manufacturing implementation, this study aims to design a smart manufacturing model in Iran's automotive industry based on the integration of the Internet of Things and Artificial Intelligence using a grounded theory approach.

2. Methods and Materials

The study was conducted using a qualitative approach and the grounded theory method (the systematic approach of Anselm Strauss & Juliet Corbin, 2015). The statistical population consisted of experts in Iran's automotive industry, including production managers, information technology specialists, senior engineers, and university faculty members. Sampling was carried out using purposive and theoretical methods with a snowball strategy until theoretical saturation was achieved, resulting in 12 in-depth semi-structured interviews. The participants included 10 men and 2 women with an average of 11 years of professional experience. The interviews lasted between 60 and 90 minutes and were transcribed within a maximum of 24 hours after each interview. Data analysis was conducted using MAXQDA 2020 software in three stages: open coding, axial coding, and selective coding. To ensure the quality of the research, the criteria proposed by Yvonna Lincoln and Egon Guba (1985) were employed. Inter-coder reliability was calculated using Cohen's kappa coefficient, which was reported as 0.86.

3. Findings and Results

The qualitative data obtained from interviews with 12 experts in Iran's automotive industry and emerging technologies, including university faculty members, senior industry managers, and information technology specialists, were analyzed using the grounded theory method based on the approach of Anselm Strauss and Juliet Corbin. The analysis resulted in the identification of 313 open codes, 176 concepts, and 36 main categories within the framework of the paradigm model. The coding process was conducted in three stages: open coding, axial coding, and selective coding, and the findings of each stage are presented sequentially.

In the open coding stage, the raw interview data were analyzed line-by-line, and the initial concepts were extracted. This process led to the identification of 313 open codes which, after analysis and categorization, were classified into 176 concepts and ultimately into 36 main categories. Table 1 presents a sample of the final grounded theory coding structure.

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Table 1

Final Grounded Theory Coding Structure

Paradigm Dimension	Main Categories	Representative Concepts/Open Codes
Causal Conditions	Technological development and innovation	Smart sensors, machine learning algorithms, big data analytics, flexible manufacturing systems, IoT-based R&D
	Specialized human resources	Specialized employee training, recruitment of skilled experts, international expert teams, learning culture
	Economic factors and implementation costs	Cost-benefit analysis, investment estimation, ROI calculation, sustainable financial resources
	Technical and communication infrastructure	Industrial internet networks, cloud infrastructure, cybersecurity systems, communication protocols
	Policy and regulatory alignment	Tax incentives, innovation support policies, government-industry collaboration, data security regulations
Core Phenomenon	Smart production process optimization	Real-time monitoring, autonomous robots, AI-based predictive maintenance, reduction of downtime
	Supply chain management and optimization	IoT-enabled supply chain monitoring, blockchain integration, logistics optimization, automated ordering systems
	Product quality enhancement	Deep learning quality inspection, intelligent quality control, predictive defect detection
	Product design innovation	AI-based CAD models, virtual reality systems, customer-oriented design, energy-efficient product design
	Customer experience transformation	Smart dashboards, personalized after-sales services, customer preference analytics
	Data and system security	Intrusion detection, data encryption, cybersecurity protocols, multi-layer security systems
Contextual Conditions	Technological infrastructure readiness	Internet speed and quality, interoperability of systems, IoT hardware accessibility
	Cultural and social environment	Acceptance of innovation, trust in digital processes, analytical data culture
	Policy and legal support	R&D funding, investment support policies, taxation policies, privacy regulations
	Human resource competencies	Big data analytics skills, interdisciplinary capabilities, operational IoT skills
	Inter-organizational interactions	Data sharing, collaboration with universities, startup partnerships, knowledge exchange
	Organizational readiness	Financial readiness, strategic vision, rapid decision-making systems, change management teams
Intervening Conditions	Infrastructure and technological barriers	Inadequate IT infrastructure, bandwidth limitations, outdated equipment
	Financial and economic challenges	High equipment costs, budget constraints, currency fluctuations
	Organizational and cultural resistance	Resistance to change, fear of job loss, weak innovation culture
	Regulatory and policy constraints	Legal complexities, sanctions-related limitations, lack of standardized regulations
	Skilled workforce limitations	Brain drain, shortage of specialized engineers, weak technical training
	Security and privacy concerns	Cybersecurity threats, data vulnerability, shortage of security specialists
	Market and demand uncertainties	Low market readiness, weak customer awareness, demand limitations
Strategies	Leadership and management strategies	Digital innovation culture, talent retention, data-driven decision-making
	Financial and economic strategies	Budget allocation, foreign investment attraction, AI-driven cost optimization
	Technological capability development	Sensor deployment, cloud platforms, predictive maintenance systems
	Support and partnership strategies	Collaboration with knowledge-based firms, university partnerships, innovation ecosystems
	Supply chain coordination	IoT-enabled logistics, component tracking, integrated supply chain data sharing
	Product and process innovation	Agile manufacturing, generative design, product personalization, energy optimization
Consequences	Productivity and efficiency enhancement	Reduced production time, lower maintenance costs, reduced human error
	Environmental transformation	Reduced energy consumption, industrial waste reduction, pollution monitoring
	Product quality improvement	Fewer manufacturing defects, compliance with international standards, intelligent quality control
	Market transformation and customer satisfaction	Faster market entry, diversified products, demand forecasting, customized services
	Financial and economic outcomes	Increased profitability, operational cost reduction, improved return on investment
	Social and cultural outcomes	Technological employment growth, skill development, promotion of innovation culture

The findings of the open coding stage demonstrated that the transition toward smart manufacturing in Iran's automotive industry is influenced by a multidimensional combination of technological, human, organizational, financial, and environmental factors. Among the identified causal conditions, technological development and innovation, together with the availability of specialized human resources, were emphasized by most participants as

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the primary driving forces behind digital transformation in manufacturing systems.

The results further revealed that the core phenomenon of smart manufacturing is not limited to production automation, but rather encompasses an integrated ecosystem involving intelligent supply chain management, customer experience transformation, advanced product design, predictive maintenance, and cybersecurity. The participants repeatedly highlighted the importance of real-time data integration and AI-driven analytics as the foundation of intelligent manufacturing systems.

The contextual conditions indicated that the successful implementation of smart manufacturing depends heavily on the readiness of technological infrastructure, organizational culture, and policy support mechanisms. In particular, organizational readiness, inter-sectoral collaboration, and workforce competencies were identified as critical facilitators that can accelerate digital transformation processes within the automotive sector.

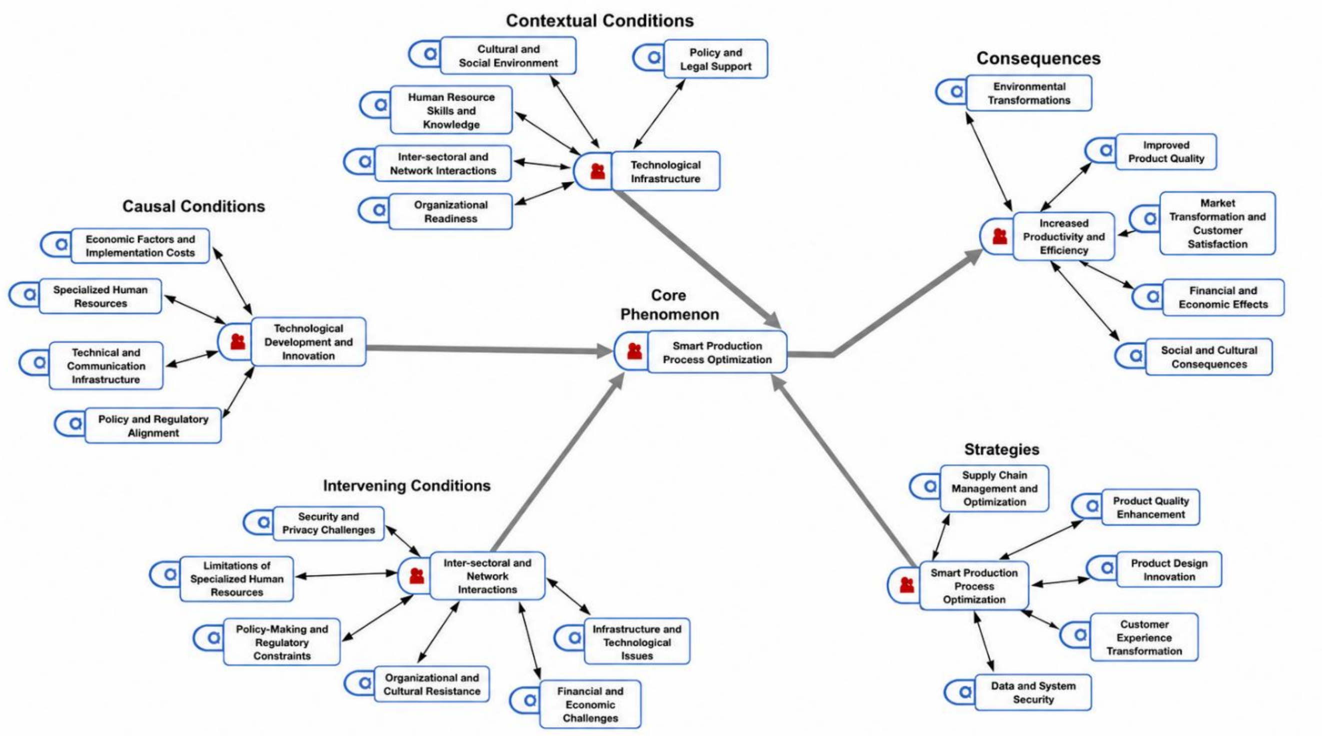
At the same time, several intervening conditions and barriers were identified. Infrastructure limitations, financial constraints, organizational resistance to change, and cybersecurity concerns emerged as the most significant challenges facing the implementation of IoT- and AI-based manufacturing systems in Iran's automotive industry. The participants also emphasized that international sanctions and regulatory ambiguities create additional obstacles to technology acquisition and system integration.

The analysis also identified several strategic pathways adopted by organizations to overcome these challenges. These strategies included strengthening digital leadership, investing in technological capabilities, establishing collaborative innovation ecosystems, and integrating IoT technologies across the supply chain. The participants stressed that sustainable financial planning and continuous workforce development are essential prerequisites for the successful execution of these strategies.

Finally, the findings demonstrated that the successful implementation of smart manufacturing can generate multidimensional consequences, including increased productivity and operational efficiency, improved product quality, enhanced customer satisfaction, environmental sustainability, and broader socio-economic development. Overall, the results suggest that smart manufacturing in Iran's automotive industry represents a systemic and dynamic transformation process requiring the simultaneous alignment of technological, organizational, human, and policy-related dimensions.

Figure 1

Final Model of the Study



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4. Discussion and Conclusion

The present study aimed to design a smart manufacturing model in Iran's automotive industry based on the integration of the Internet of Things and Artificial Intelligence using a grounded theory approach. The findings demonstrated that smart manufacturing in the automotive industry is a multidimensional and systemic phenomenon shaped by the interaction of technological, organizational, environmental, economic, and human factors. The final paradigm model identified causal conditions, contextual conditions, intervening conditions, strategic actions, and multidimensional consequences associated with the implementation of intelligent manufacturing systems. The results indicate that the transition toward smart manufacturing cannot be understood solely as a technological transformation; rather, it represents a comprehensive organizational and industrial transformation requiring simultaneous alignment among digital infrastructure, managerial capabilities, workforce competencies, policy frameworks, and innovation ecosystems.

One of the major findings of the study was the identification of technological development and innovation as one of the primary causal drivers of smart manufacturing transformation. The participants emphasized the importance of intelligent sensors, machine learning algorithms, predictive analytics, cloud computing, and real-time monitoring systems in enabling intelligent production processes. This finding is consistent with previous studies highlighting the central role of Industry 4.0 technologies in manufacturing transformation (Elnadi, 2023; Liao et al., 2019). The present findings further support the argument that AI and IoT integration creates intelligent production ecosystems capable of adaptive and autonomous operational management (Kodumuru, 2025). Similarly, studies in automotive manufacturing have shown that AI-driven systems improve production flexibility, predictive capabilities, and process optimization (Gao et al., 2024; Rodic et al., 2021). Therefore, the findings confirm that technological innovation represents the foundational infrastructure for digital transformation in automotive production systems.

Another important result of the study was the identification of specialized human resources as a critical enabling factor in smart manufacturing implementation. The participants repeatedly emphasized the importance of employee training, interdisciplinary competencies, digital literacy, and the presence of highly skilled experts capable of managing advanced technological systems. This finding aligns with prior research demonstrating that human resource competencies significantly influence the success of Industry 4.0 initiatives (Hakim & Syahputra, 2023; Rezaei & Farahani, 2023). Smart manufacturing environments require employees capable of working with data analytics, AI algorithms, intelligent robotics, and interconnected production systems. In this regard, the findings support the perspective that digital transformation is not purely technology-oriented but also highly dependent on organizational learning and workforce development. The importance of specialized competencies becomes even more significant in developing economies where technological knowledge gaps and shortages of skilled professionals may hinder digital transformation processes.

The study also revealed that economic and infrastructural conditions significantly affect the implementation of intelligent manufacturing systems. Participants identified investment costs, financial sustainability, communication infrastructure, industrial internet networks, cybersecurity systems, and cloud infrastructure as major causal conditions influencing smart manufacturing adoption. These findings are consistent with earlier studies emphasizing the importance of technological readiness and infrastructure availability for Industry 4.0 implementation (Ghobakhloo, 2020; Moghaddasi et al., 2020). Smart manufacturing systems require substantial investments in digital infrastructure, hardware integration, intelligent communication systems, and cybersecurity protections. Moreover, the Iranian automotive industry faces unique financial and technological constraints resulting from economic instability, sanctions, and restricted access to advanced technologies. Consequently, infrastructure development emerges as a strategic prerequisite for achieving industrial digital transformation.

The findings related to the core phenomenon demonstrated that smart manufacturing in the automotive industry extends beyond production automation and encompasses a broader ecosystem of interconnected technological and managerial functions. The identified dimensions included smart production process optimization, intelligent supply chain management, product quality enhancement, AI-based product design, customer experience transformation, and cybersecurity management. These findings are strongly aligned with contemporary Industry 4.0 literature emphasizing the integrated nature of

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smart manufacturing ecosystems (Liu, 2025; Soori, 2023). The integration of AI and IoT technologies enables automotive manufacturers to establish real-time visibility across production systems, improve operational responsiveness, and enhance decision-making quality. Furthermore, the findings regarding predictive maintenance and intelligent quality control correspond closely with prior studies demonstrating the effectiveness of AI-based defect detection and predictive analytics in reducing downtime and improving manufacturing reliability (Ajithkumar & Babu, 2025; Morales-Matamoros et al., 2025).

The results also highlighted the strategic importance of supply chain optimization and digital coordination in automotive manufacturing systems. Participants emphasized IoT-enabled logistics management, blockchain integration, intelligent inventory systems, and automated ordering mechanisms as key dimensions of smart manufacturing. These findings align with research indicating that digital transformation significantly improves supply chain visibility, operational synchronization, and resource optimization within automotive industries (Tawfeeq Saleh Al-Sammarraie & Fathi, 2025; Wang et al., 2021). The integration of intelligent technologies across supply chain networks enables organizations to reduce uncertainty, improve forecasting accuracy, and increase operational resilience. In the context of Iran's automotive industry, where supply chain disruptions and operational inefficiencies remain significant challenges, digital coordination mechanisms may substantially enhance manufacturing sustainability and competitiveness.

Another major finding concerned the role of contextual conditions facilitating smart manufacturing implementation. The participants emphasized the importance of organizational readiness, cultural acceptance of innovation, policy support mechanisms, and inter-sectoral collaboration. This finding supports previous studies demonstrating that digital transformation success depends heavily on organizational culture, managerial commitment, and institutional support (Llopis-Albert, 2021; Mozafari Mehr & Taghavifard, 2024). Organizations with adaptive cultures and innovation-oriented leadership are more capable of embracing technological change and managing digital transformation processes effectively. Moreover, the findings suggest that collaboration among universities, technology firms, government agencies, and manufacturing organizations can accelerate technological innovation and knowledge transfer within the automotive sector.

The identification of intervening conditions and barriers represented another significant contribution of the study. Participants identified infrastructure limitations, financial constraints, organizational resistance, cybersecurity threats, regulatory complexities, and shortage of specialized personnel as major obstacles to smart manufacturing implementation. These findings are highly consistent with prior studies investigating Industry 4.0 barriers in developing economies (Hakim & Syahputra, 2023; Moghaddasi et al., 2020). Resistance to organizational change emerged as a particularly important barrier because employees often perceive intelligent automation technologies as threats to job security and existing work routines. Similarly, cybersecurity concerns and data vulnerabilities were viewed as major risks associated with interconnected manufacturing systems. These findings demonstrate that successful implementation of smart manufacturing requires not only technological investment but also organizational trust-building, workforce engagement, and institutional readiness.

The study further demonstrated that strategic management actions play a decisive role in overcoming implementation barriers and facilitating digital transformation. The identified strategies included digital leadership development, investment planning, technological capability enhancement, collaborative innovation ecosystems, supply chain integration, and agile manufacturing processes. These findings correspond closely with studies emphasizing the importance of strategic alignment and leadership commitment in Industry 4.0 implementation (Falahat, 2023; Rezaei & Farahani, 2023). Organizations capable of establishing data-driven decision-making cultures and innovation-oriented management systems are more likely to achieve successful digital transformation outcomes. The findings also suggest that collaboration with universities, startups, and knowledge-based companies can facilitate technological adaptation and reduce implementation uncertainties.

An important aspect of the findings was the identification of multidimensional consequences resulting from successful smart manufacturing implementation. These consequences included increased productivity, operational efficiency, product quality improvement, environmental sustainability, financial performance enhancement, and social development outcomes. These findings are consistent with prior research emphasizing the positive effects of Industry 4.0 technologies on manufacturing sustainability and industrial competitiveness

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(Elnadi, 2023; Ghobakhloo, 2020). The participants specifically highlighted reductions in production downtime, maintenance costs, human error, and energy consumption as key operational outcomes of intelligent manufacturing systems. Moreover, the findings regarding environmental benefits support the argument that digital manufacturing technologies can contribute significantly to sustainable industrial development through resource optimization and intelligent energy management (Tawfeeq Saleh Al-Sammarraie & Fathi, 2025).

The findings also revealed that smart manufacturing contributes to market transformation and customer satisfaction enhancement. Intelligent production systems facilitate product customization, reduce time-to-market, and improve after-sales service quality. These findings align with previous studies emphasizing the role of AI and digital technologies in improving customer responsiveness and product innovation within automotive industries (Falahat, 2023; Kruachottikul, 2023). Modern automotive consumers increasingly demand personalized products, rapid service delivery, and digitally integrated customer experiences. Consequently, smart manufacturing systems provide organizations with strategic advantages in responding to evolving market expectations and competitive pressures.

The final grounded theory model developed in this study demonstrates that smart manufacturing transformation in Iran's automotive industry is fundamentally systemic, dynamic, and context-dependent. The interaction among causal drivers, contextual facilitators, implementation barriers, strategic responses, and organizational consequences illustrates the complexity of digital transformation processes within industrial environments. Unlike linear technology adoption models, the present findings indicate that smart manufacturing implementation involves continuous interactions among technological, organizational, environmental, and human dimensions. Therefore, successful digital transformation requires integrated managerial approaches capable of simultaneously addressing technological infrastructure, organizational culture, workforce development, financial investment, and institutional coordination.

The study contributes to the existing literature by providing an indigenous and context-specific framework for understanding smart manufacturing transformation in Iran's automotive industry. While previous studies primarily focused on isolated technological dimensions or implementation challenges, the present research offers a comprehensive paradigm model explaining the interrelationships among multiple organizational and environmental factors shaping smart manufacturing adoption. The findings also extend grounded theory applications within Industry 4.0 research by providing a multidimensional conceptualization of AI- and IoT-based manufacturing transformation in a developing industrial context.

One limitation of the present study is that the findings were derived from qualitative interviews with a relatively limited number of experts within Iran's automotive industry. Although theoretical saturation was achieved, the perspectives obtained may not fully represent all manufacturing organizations, stakeholders, or industrial sectors. In addition, the study focused specifically on the automotive industry, which may limit the generalizability of the findings to other industrial contexts. Another limitation concerns the rapidly evolving nature of Industry 4.0 technologies, meaning that technological developments and organizational practices may change over time.

Future research is recommended to quantitatively validate the proposed paradigm model using structural equation modeling or mixed-method approaches. Comparative studies across different industrial sectors and countries may also provide broader insights into the contextual differences affecting smart manufacturing implementation. Furthermore, future investigations may examine the role of emerging technologies such as blockchain, generative AI, and advanced digital twin systems in shaping next-generation manufacturing ecosystems. Longitudinal studies are also suggested to evaluate the long-term organizational and economic impacts of digital transformation initiatives in manufacturing industries.

From a practical perspective, policymakers and industrial managers should prioritize the development of digital infrastructure, cybersecurity systems, and intelligent communication networks to facilitate smart manufacturing implementation. Organizations should also invest heavily in workforce training, interdisciplinary skill development, and innovation-oriented organizational cultures. Strengthening collaboration among universities, technology firms, startups, and manufacturing companies can accelerate technological learning and industrial innovation. In addition, supportive governmental policies, financial incentives, and strategic investment programs are necessary to reduce implementation barriers and support the digital transformation of Iran's automotive industry.

Authors' Contributions

All authors equally contributed to this study.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethics Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

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