Application of the importance-performance matrix in analyzing lean manufacturing indicators based on circular economy in the automotive industry

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ABSTRACT

The purpose of this study is to examine and analyze the importance-performance matrix (IPMA) of key factors influencing the manufacturing of lean products with a circular economy approach in the context of Industry 4.0 within the automotive sector. The statistical population consisted of industry experts and automotive specialists, and the data were analyzed using the Importance-Performance Matrix Analysis (IPMA). The findings revealed that factors such as the adoption of advanced technologies and the implementation of lean manufacturing are among the industry's strengths and should be sustained. Meanwhile, certain elements, including waste reduction and supply chain optimization, were found to have high importance but weaker performance, necessitating targeted improvements. In contrast, factors such as economic sanctions and rising costs were identified as critical threats requiring immediate action. The absence of any components in the low-importance, low-performance quadrant indicates the industry's appropriate focus on strategic priorities.

Keywords: Lean manufacturing, automotive industry, Industry 4.0, importance-performance matrix (IPMA)

1. Introduction

The automotive industry, as one of the main drivers of the global economy, is constantly exposed to rapid technological advancements, increasingly stringent environmental requirements, and intense market competition. In this context, the lean manufacturing approach, developed to eliminate non-value-added activities and reduce resource waste, has been recognized as an effective strategy for enhancing organizational performance. This production method has gained significant traction in automotive companies due to its ability to increase productivity, improve quality, and reduce costs. However, its sustained and effective long-term implementation faces complex challenges.

In the past decade, the emergence of advanced technologies associated with the Fourth Industrial Revolution has enabled a reevaluation of traditional production models. Concepts such as intelligent processes, the Internet of Things (IoT), and extensive automation have paved the way for a transformative shift in the automotive value chain. These technologies help companies align lean manufacturing strategies with dynamic market conditions while enhancing flexibility and reducing costs.

Meanwhile, the circular economy approach has gained considerable attention as an emerging framework for resource management and waste reduction. Unlike the traditional linear "take-make-dispose" model, this paradigm emphasizes returning resources to the production cycle through reuse, remanufacturing, and effective recycling, a pathway that aligns with lean principles. Given the automotive industry's significant environmental footprint, this approach holds particular relevance in fostering sustainable manufacturing practices.

While scattered studies have independently examined each of these concepts—lean manufacturing, Industry 4.0, and circular economy—a comprehensive study that simultaneously analyzes and evaluates these three approaches in the automotive industry remains scarce. The necessity to comply with environmental expectations and the need for innovation in production processes have driven automotive manufacturers toward adopting integrated solutions.

This study aims to identify and analyze the key factors influencing the successful implementation of lean manufacturing within the framework of circular economy and Industry 4.0 technologies, with a focus on the automotive sector. To achieve this, a mixed-method approach is adopted, utilizing thematic analysis for extracting key indicators and the Importance-Performance Matrix Analysis (IPMA) to assess their performance and significance. The outcome of this research is the development of a conceptual model for integrating modern production approaches in the automotive industry, providing practical insights for industrial decision-makers and policymakers.

The core research question is which components have the greatest impact on the synergy between lean manufacturing, circular economy, and Industry 4.0, and how their status can be evaluated in terms of importance and performance. The paper's structure includes a review of theoretical foundations and prior studies, methodology description, data analysis and results presentation, and finally, conclusions and recommendations.

Literature Review and Research Background

The origins of the lean manufacturing approach trace back to the Toyota Production System in the 1970s, where efforts to enhance efficiency and eliminate waste transformed it into a fundamental component of modern production management. This philosophy aims to maximize customer value by eliminating non-value-adding activities, referred to as waste, which not only reduce productivity but also incur unnecessary costs (Soliman, 2024). Consequently, lean principles emphasize process simplification, resource optimization, and the elimination of non-essential bottlenecks (Campbell et al., 2020).

In recent years, lean manufacturing has leveraged tools such as value stream mapping, visual management, and pull systems to significantly reduce waste and excess inventory (Roessler & Ruse, 2019). These benefits, including minimized material movement, improved workflow, and the elimination of redundant activities, have contributed to cost reduction and enhanced organizational productivity (Sini et al., 2020; Black & Kohser, 2020).

The advent of Industry 4.0 technologies, such as IoT, artificial intelligence, and cyber-physical systems, has opened new avenues for advancing lean production models. Industry 4.0 enables companies to predict potential failures and optimize equipment performance through real-time data analytics. This technological synergy has been instrumental in reducing excess inventories and improving production responsiveness (Wagner et al., 2017). As a result, the integration of lean manufacturing with digital capabilities is now recognized as a key strategy in advanced supply chain management (Razavi et al., 2023).

In this context, the concept of the circular economy has emerged as an alternative to linear production and consumption models. Unlike traditional approaches where products end their lifecycle after consumption, this paradigm emphasizes reintegrating materials and resources into the production cycle through recycling, reuse, and remanufacturing (Murray et al., 2017). In industries like automotive manufacturing, the circular economy can significantly reduce environmental footprints, conserve natural resources, and enhance efficiency (Bordari & De Souza, 2024).

The convergence of these three approaches (lean manufacturing, Industry 4.0 technologies, and the circular economy) enables the creation of an advanced and sustainable production system. This integration not only optimizes resource utilization and operational efficiency but also addresses environmental challenges and competitive pressures (Razavi et al., 2023). The following section reviews key studies in this research domain:

Maware and Parsley (2022) conducted a study examining the role of Industry 4.0 in enhancing lean production processes and achieving long-term sustainability. Based on data collected from 65 manufacturing organizations in the United States and employing quantitative methods with structural equation modeling, the research demonstrated that to attain sustainable performance, industry managers must integrate Industry 4.0 technologies, such as the Internet of Things (IoT), cloud computing, robotics, and augmented reality, alongside lean manufacturing principles. The findings revealed that the synergy between these technologies and lean production can improve economic, social, and environmental indicators. Mahboob kheirkhah et al. (2025) proposed a production model for the automotive industry emphasizing lean manufacturing and the circular economy in the Industry 4.0 era. The results identified six key dimensions, namely product design, supply chain, economic sanctions, production processes, advanced technologies, and recycling/reuse. The study found that product design directly influences production processes, the supply chain plays a critical role in raw material procurement, and sanctions can restrict supply chain operations and the adoption of advanced technologies. Advanced technologies contribute to production optimization and waste reduction, while production processes impact recycling and reuse efforts. Similarly, Kaliyan et al. (2023) conducted research in India's automotive sector to identify and analyze key success factors for implementing sustainable production. Using a mixed-method approach incorporating questionnaires, statistical tests, and qualitative analysis, they examined the relationship between lean manufacturing and sustainable performance. The results indicated that properly implemented lean initiatives can significantly enhance economic, social, and environmental performance. The study also provided actionable strategies for successful lean adoption in India’s automotive industry, offering valuable insights for similar industries in developing economies. A study by Yu et al. (2022) examined the impact of Industry 4.0 technologies and circular economy practices on automotive industry performance. The results demonstrated that proper implementation of these technologies plays a significant role in enhancing manufacturing system productivity, particularly regarding sustainable raw material procurement and resource reuse. The study also revealed that coordination between supply chains and recycling strategies positively correlates with economic performance indicators, leading to improved organizational financial health. In another study, Sari et al. (2021) investigated sustainability dimensions in lean manufacturing with a focus on environmental indicators. Using quantitative and qualitative methods, they analyzed variables such as energy consumption, production waste, and maintenance processes, demonstrating that lean manufacturing, when implemented alongside environmental standards, can directly impact productivity growth and customer satisfaction. Sahoo (2020) evaluated lean manufacturing implementation in small and medium automotive enterprises in India. Using a qualitative approach with in-depth interviews of industry managers, the research examined lean implementation challenges and their impact on process standardization improvement. Results indicated that quality culture, employee training, and continuous improvement approaches were key success factors. Agyemang et al. (2019) conducted research examining drivers and barriers to circular economy implementation in Pakistan's automotive industry. Employing a mixed-methods approach including questionnaires, Excel data analysis, and semi-structured interviews, they collected and analyzed necessary data. Findings revealed that profitability, market share, cost reduction, and environmental/social responsibility concerns were primary motivational factors for circular economy adoption. Conversely, three main implementation barriers were identified, namely lack of awareness, financial constraints, and expertise shortages. These findings emphasize that successful circular economy realization requires addressing both economic motivations and structural/knowledge barriers. In a study conducted by Zarepour (2022) aimed at identifying, evaluating, and reducing production system waste based on lean manufacturing principles, the Value Stream Mapping (VSM) tool was employed. This research was carried out at an Iranian automotive parts manufacturing company, focusing on improving key indicators such as cost, time, productivity, and efficiency. The results of VSM implementation demonstrated significant reduction in total production process time. Consequently, reduced production time led to lower costs and decreased workforce requirements. These changes resulted in enhanced productivity and production line efficiency. Furthermore, the production system transitioned from push to pull, indicating optimized manufacturing processes. In research conducted by Jazaeri and Amin Mousavi (2021), the identification and prioritization of lean manufacturing tools for improving productivity was examined. This study applied the TOPSIS multi-criteria decision-making method at SAIPA Automotive Company. The research evaluated 16 lean tools including Total Quality Management, artificial intelligence implementation, waste identification, and productivity-related tools. Additionally, seven types of production waste were identified, including overproduction, unnecessary transportation, and defective production. Pourgolzari's study (2018) focused on lean manufacturing's impact on organizational competitive advantage. Conducted at Iran Khodro Company using structural equation modeling and path analysis, the research demonstrated that lean manufacturing significantly enhances competitive advantage through cost reduction, waste elimination, and inventory optimization. Izadmehr (2016) investigated lean system implementation at Pars Khodro Company using fuzzy DEMATEL decision-making and SAE J4000 standard. Results indicated that production flexibility, quality improvement, production process management, and employee performance data had the greatest impact on successful lean system implementation. In another study in this domain, Bayat examined lean manufacturing implementation at Pars Khodro Company. Findings revealed a 52.8% lean adoption rate, indicating average performance. Key success factors included lean production systems, Total Quality Management processes, and flexibility.

Given the research background and the aforementioned context, this study aims to identify the key success factors for the concurrent implementation of these three approaches in the automotive industry by integrating qualitative and quantitative methods. Employing thematic analysis to extract critical indicators and Importance-Performance Matrix Analysis (IPMA) to evaluate them will provide a coherent framework for strategic decision-making and sustainable development in this sector.

Methodology

This study is applied in purpose and exploratory in data collection, adopting a mixed-methods approach. For the qualitative phase, data were collected through in-depth interviews and analyzed using thematic analysis. In the quantitative phase, data were gathered via questionnaires and analyzed using the Importance-Performance Matrix Analysis (IPMA). Participants included managers and experts from Iran’s Ministry of Industry, Mine and Trade (MIT), Iran Khodro and SAIPA automotive companies, as well as university professors. The study was conducted over twelve months, from October 2023 to September 2024. Qualitative sampling employed a non-probabilistic judgmental method. Researchers first compiled a list of domain experts, then conducted interviews with willing participants. For the quantitative phase, convenience sampling was used, with data collected from 384 automotive specialists based on Cochran’s formula. The IPMA evaluates gaps between expectations (importance) and perceptions (performance) to identify key improvement areas. This analysis reveals determinants with relatively high importance but low performance, plotted on a two-dimensional grid where the Y-axis represents importance and the X-axis performance. Known as the IPMA matrix, it consists of four quadrants, each indicating specific strategic priorities. The matrix supports decision-making by highlighting improvement opportunities based on the disparity between desired (importance) and current (performance) states (Figure 1).

First Quadrant (Sustaining Current Strategies): This quadrant is considered one of the organization's key strengths and should be sustained. Here, the importance of the process is very high, and its performance is strong. Therefore, the processes in this quadrant must be maintained and strengthened as competitive advantages.

Second Quadrant (Resource Waste): In this quadrant, the metrics are of low importance, while the company's performance in this area is high. In other words, this section indicates resource wastage because the resources allocated to these features exceed actual needs and could be better utilized elsewhere. This situation is known as the quadrant model. In this region, although the importance of the process is low, its performance is strong, meaning the processes in this section lead to resource wastage within the organization and should be corrected or optimized in some way.

Third Quadrant (Neglect): In this quadrant, the identified factors are of low importance, and the organization also performs poorly in these metrics. Since these factors are not very significant, the organization should not allocate excessive resources to this area and should only use limited resources for it.

Fourth Quadrant (Improvement and Investment Priorities): In this region, the importance of the process is very high, but its performance is weak. Therefore, the processes in this section require special attention and improvement. These processes are important to stakeholders, but the organization's performance in this domain is low. This quadrant highlights the weaknesses of the organization or company, and failure to identify these characteristics can lead to low customer satisfaction. Thus, efforts to improve this section should be a top priority, as key weaknesses exist in this area.

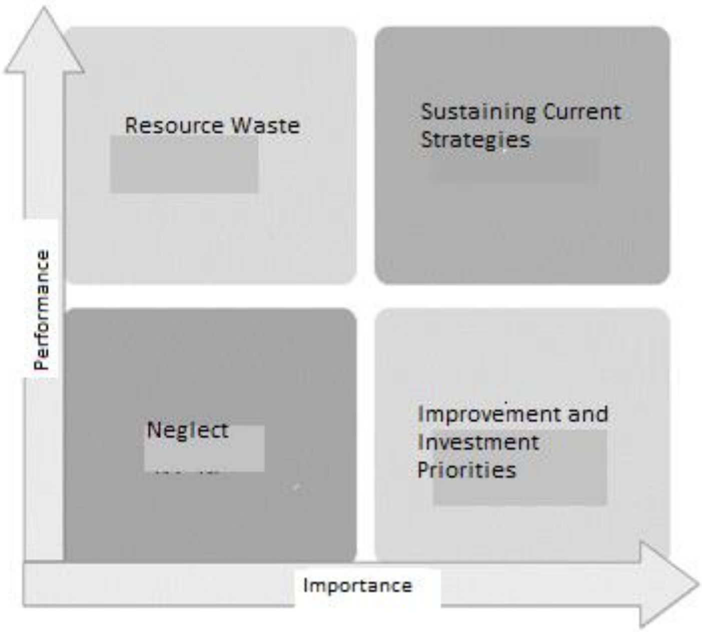


Figure 1- Importance-Performance Analysis Matrix

Findings

Identification of Dimensions and Components

This research used interviews to collect qualitative data and employed thematic analysis. Following a literature review, a framework was developed to formulate interview questions with experts, aiming to gather qualitative data. Subsequently, a total of 17 individuals, including university professors and managers and specialists from the Ministry of Industry, Mine and Trade (IMT) and two Iranian automotive companies, namely Iran Khodro and SAIPA, were selected through judgmental sampling. In the second phase, the conducted interviews were coded using Braun and Clarke’s (2006) six-step inductive thematic analysis. As indicated by the results, the components of lean production in automotive companies within the circular economy of Industry 4.0 could be identified and determined under six main components of product design, supply chain, sanctions, production process, the use of advanced technology, and recycling and reuse, along with 18 sub-components (for further reading, refer to Mahboob Kheirkhah et al., 2026). Demographic information of the statistical population revealed that, in terms of gender, 67% were men and 33% were women. Regarding age, 41% of respondents were between 28 and 30 years old, 32% were between 30 and 35, and 27% were over 35. In terms of work experience, 56% had 5 to 10 years, 33% had 10 to 15 years, and 11% had 15 to 20 years of experience. Regarding education, 56% held a bachelor’s degree, 33% a master’s degree, and 11% a Ph.D.

Importance-Performance Analysis

In this step, the importance and performance of each main component affecting production in the automotive industry, with an emphasis on lean production and the circular economy in the era of Industry 4.0, were examined to assess the desirability and feasibility of potential changes. Here, "importance" refers to the total effect coefficient, including the direct and indirect effects of one variable on another in the path model, which can be understood as the explanatory or predictive power of one variable for another. In the importance-performance matrix, the horizontal axis represents importance, and the vertical axis represents performance. On this basis, variables with high importance and low performance provide the best conditions for intervention. Accordingly, descriptive and inferential statistics are presented in the following section.

Based on the results obtained from Table 2, the T-statistic indicates the significance of the relationships between the model’s variables, as the probability value is less than 0.05. In other words, the significance test of the path coefficients shows that all paths are statistically significant, and their effects are confirmed. This means that the components formulated in the research model have appropriate reliability. Additionally, the results of examining the composite reliability coefficients showed that the values of these indicators for all latent variables are greater than 0.7, thus confirming the reliability of the measurement tools using this indicator. Furthermore, the results of examining the extracted variance values of the latent variables in the study indicated that all variables obtained values above 0.5. It can be stated that the convergent validity of the measurement tools was confirmed by using the extracted average variance index.

Subsequently, since the importance-performance analysis focuses on a target construct as a key objective of interest in the PLS path model, the first step in creating the importance-performance map requires selecting the target construct of interest. In this research, the outcomes were selected as the target construct. Accordingly, the measurement model was fitted and presented using the Importance-Performance Map Analysis (Figure 2).

It is worth noting that when conducting importance-performance analysis at the level of main indicators, the average value of an indicator represents its average performance. Accordingly, the importance-performance results of the predictive constructs for the production process are presented in Table 3.

Table 2. Results of the Structural Model Execution

Path Coefficients	Standard Deviation	T-Statistic	Probability Values	Result
Product Design -> Production Process	0.465	0.011	42.465	0.000
Production Process -> Recycling and Reuse	0.661	0.016	41.5	0.000
Use of Advanced Technology -> Production Process	0.308	0.008	40.224	0.000
Establishing a Transparent and Sustainable Supply Chain -> Supply Chain	0.483	0.015	31.96	0.000
Collaboration with Suppliers to Reduce Waste and Lower Costs -> Supply Chain	0.442	0.016	28.116	0.000
Use of Digital Technologies for Tracking Materials and Products -> Use of Advanced Technology	0.333	0.012	27.588	0.000
Implementation of Smart Systems for Process Optimization -> Use of Advanced Technology	0.326	0.013	25.468	0.000
Use of Modern and Advanced Technologies to Improve Efficiency and Reduce Costs in Production Processes -> Use of Advanced Technology	0.322	0.013	24.754	0.000
Changes in Product Design -> Sanctions	0.297	0.012	24.722	0.000
Development of Internal Collaborations -> Production Process	0.108	0.005	23.916	0.000
Use of Sustainable and Eco-Friendly Materials in Production -> Production Process	0.104	0.005	23.04	0.000
Focus on Quality and Waste Reduction -> Production Process	0.111	0.005	22.524	0.000
Reduced Productivity -> Sanctions	0.288	0.013	21.972	0.000
Supply Restrictions -> Sanctions	0.205	0.011	19.477	0.000
Designing Products with Recyclability, modifiability, and Upgradability Features -> Product Design	0.45	0.024	18.778	0.000
Design for Easy Disassembly of Components -> Product Design	0.572	0.024	23.57	0.000
Collaboration with Manufacturers to Establish Recycling Systems -> Recycling and Reuse	0.135	0.01	13.657	0.000
Creating a Market for Recycled Products -> Recycling and Reuse	0.129	0.01	12.338	0.000
Designing Efficient Systems for Recycling and Reusing Products and Components -> Recycling and Reuse	0.115	0.011	10.732	0.000
Sanctions -> Supply Chain	-0.13	0.012	10.777	0.000
Sanctions -> Use of Advanced Technology	-0.105	0.01	10.053	0.000
Increase in Production Costs -> Sanctions	0.306	0.012	25.72	0.000
Supply Chain -> Production Process	-0.046	0.007	6.63	0.000

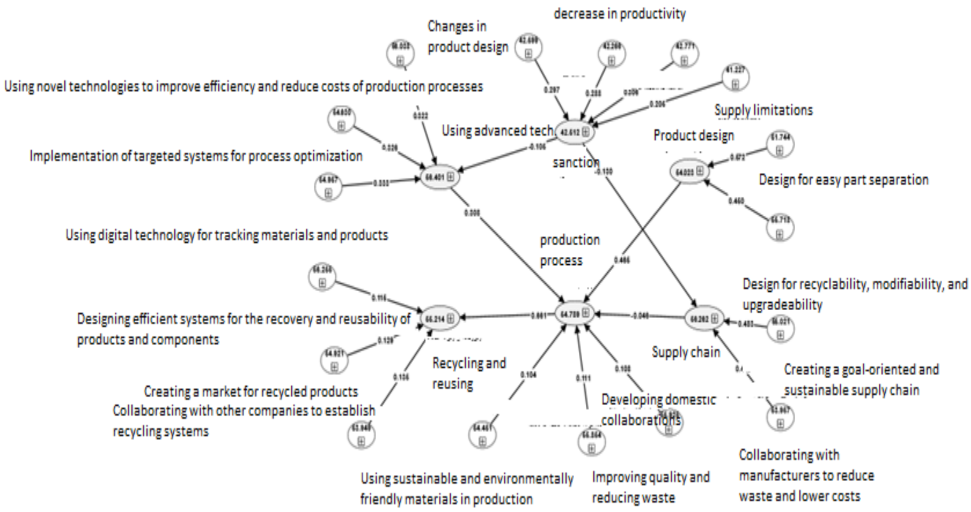


Figure 2. Measurement Model with Importance-Performance Analysis (IPMA)

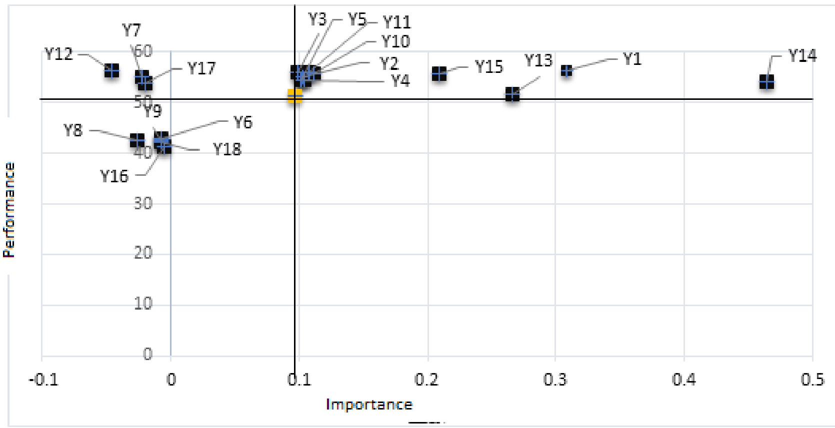
The dispersion of the information map shown in Table 3 allows for the creation of an importance-performance map for the predictive indicators of the research model. The x-axis represents the importance of producing lean products in the circular economy of Industry 4.0 for automotive companies, while the y-axis shows the performance of producing lean products in the circular economy of Industry 4.0 for automotive companies in terms of the rescaled variable scores. For better orientation, two additional lines are applied in the importance-performance map: the average importance (i.e., a vertical line) and the average performance (i.e., a horizontal line), as displayed in Figure 3. According to the results, the production process of lean products in the circular economy of Industry 4.0 for automotive companies has an average importance of 0.096 and an average performance of 51.464. These two additional lines divide the importance-performance map into four sections, where the values of importance and performance are approximately above average.

According to Figure 3, the Importance-Performance Matrix analysis for the component is as follows:

First Quadrant (Sustaining Current Strategy – Optimal Use of Technology and Lean Design): This quadrant is recognized as the main strength of the automotive industry, and current strategies in this area should be continued. This section includes the use of advanced and digital technologies for tracking materials and products (Y2), improving efficiency and reducing costs in production processes through modern technologies (Y3), and utilizing sustainable and environmentally friendly materials in production (Y4). Additionally, the implementation of smart systems for process optimization (Y5), a focus on quality and waste reduction (Y10), the development of internal collaborations (Y11), and designing products with recyclability, repairability, and upgradability (Y15) fall within this quadrant. These processes are maintained as competitive advantages for automotive companies and should be further developed with greater attention. Designing for easy disassembly of components (Y13) and product design (Y14) are also among the key strategies in this quadrant, contributing to the long-term success of the automotive industry.

Table 3. Importance-Performance Results of Predictive Constructs for the Production Process

Indicator	Symbol	Importance	Performance
Use of advanced technology	Y1	0.308	56.401
Use of digital technologies for tracking materials and products	Y2	0.103	54.957
Use of modern and advanced technologies to improve efficiency and reduce costs in production processes	Y3	0.099	56.038
Use of sustainable and environmentally friendly materials in production	Y4	0.104	54.451
Implementation of smart systems for process optimization	Y5	0.101	54.630
Increase in production costs	Y6	-0.008	42.771
Establishment of a transparent and sustainable supply chain	Y7	-0.022	55.021
Sanctions	Y8	-0.026	42.512
Changes in product design	Y9	-0.008	42.599
Focus on quality and waste reduction	Y10	0.111	55.854
Development of internal collaborations	Y11	0.108	55.925
Supply chain	Y12	-0.046	56.262
Design for easy disassembly of parts	Y13	0.266	51.744
Product design	Y14	0.465	54.023
Design of recyclable, repairable, and upgradable products	Y15	0.209	55.718
Supply constraints	Y16	-0.005	41.227
Collaboration with suppliers to reduce waste and costs	Y17	-0.020	53.957
Decrease in productivity	Y18	-0.008	42.266
Average		**0.096**	**51.464**



Second Quadrant (Resource Waste – Supply Chain and Waste Reduction Collaborations): In this quadrant, criteria such as establishing a transparent and sustainable supply chain (Y7), overall supply chain management (Y12), and collaboration with suppliers to reduce waste and lower costs (Y17) are included. Although these areas have relatively low importance, companies' performance in them is high. This situation indicates resource wastage, meaning that excessive resources have been allocated to these sections. To prevent resource waste, companies must manage these processes optimally to achieve greater productivity.

Third Quadrant (Neglect): This quadrant contains no variables. This indicates that, in this study, no factor in the automotive industry has been identified as having both low importance and weak performance. This result may suggest that the automotive industry has successfully avoided focusing on unimportant and ineffective factors.

Forth Quadrant (Improvement and Investment Priorities – Managing Production and Supply Challenges): This quadrant includes factors that are highly important but exhibit weak performance, requiring improvement. These factors include rising production costs (Y6), sanctions (Y8), changes in product design (Y9), supply constraints (Y16), and reduced productivity (Y18). These factors have been identified as weaknesses of the automotive industry, and neglecting them could reduce customer satisfaction. Therefore, the automotive industry must strive to address these weaknesses by improving these areas and investing appropriately to enhance performance in these fields.

Discussion and Conclusion

The results of this research, through the analysis of the importance-performance matrix of indicators affecting lean production in the automotive industry with an emphasis on the circular economy and Industry 4.0, revealed that this industry has managed to demonstrate successful performance in some key areas, while in others, there is a need for further improvement and focus. In this regard, the first quadrant of the importance-performance matrix includes factors that are both highly important and areas where the automotive industry's performance is very strong. These factors include the use of advanced technologies to improve efficiency and reduce costs in production processes, the utilization of sustainable and environmentally friendly materials in production, the implementation of smart systems for process optimization, and the design of products with recyclability, repairability, and upgradability features. Additionally, a focus on quality and waste reduction, the development of internal collaborations, and product design also fall within this quadrant. These factors demonstrate the automotive industry's ability to effectively leverage modern technologies and implement sustainable designs. These companies have been able to use these factors as competitive advantages and solidify them as part of their long-term strategies. As a result, the automotive industry should continue to reinforce and pursue these strategies. Maintaining and expanding these processes can help sustain a competitive edge in global markets and, in alignment with the principles of the circular economy, lead to waste reduction and improved sustainability in the industry. Further investment in these areas and the adoption of cutting-edge technologies can enhance efficiency and reduce costs in the long term.

In the second quadrant, the automotive industry has performed well in certain areas, even though these factors are considered less important. These factors include establishing a transparent and sustainable supply chain, overall supply chain management, and collaborating with suppliers to reduce waste and costs. This situation indicates a misallocation of resources, meaning that excessive resources may have been allocated to these factors beyond actual needs. While these areas are important in their own right, the high performance of companies in these domains could imply that the resources dedicated to them have exceeded requirements and should be optimized. Consequently, automotive companies should reassess the resources allocated to these factors. Greater focus should be placed on areas falling within the fourth quadrant, as these areas require more improvement and investment. Optimizing and reducing resources allocated to these sections can lead to enhanced overall productivity and prevent resource wastage.

In the third quadrant, no factors have been identified. This means that in this research, there are no factors that are both low in importance and low in performance. The absence of factors in the third quadrant may indicate that automotive companies have successfully maintained their focus on key and important factors while avoiding allocating resources to less significant and ineffective areas. Consequently, the lack of factors in the third quadrant reflects good resource management and appropriate attention to priorities in the automotive industry. Companies should continue this approach and refrain from focusing on less critical factors that provide minimal added value. This can help improve overall efficiency and prevent resource wastage.

The fourth quadrant includes factors that are of high importance, yet companies' performance in these areas is weak. These factors include rising production costs, sanctions, changes in product design, supply constraints, and declining productivity. This situation highlights vulnerabilities in production processes and supply chains that require immediate attention and improvement. Weaknesses in these areas can negatively impact the competitiveness of automotive companies and lead to decreased customer satisfaction. As a result, automotive companies must consider these areas as top priorities for improvement and investment. Enhancing the identified areas in this quadrant can significantly increase productivity, reduce costs, and improve product quality. Focusing on addressing these weaknesses and managing production and supply challenges can help maintain and enhance companies' competitiveness in global markets.

Based on the findings of the present study and their comparison with previous research, several key points can be highlighted. The current study demonstrated that product design and supply chain are among the critical factors influencing the production process in the automotive industry. These findings align with the results of similar studies in the literature. For instance, Maware and Parsley’s (2023) research emphasized that Industry 4.0-related technologies, such as big data and the Internet of Things (IoT), can enhance lean production performance and long-term sustainability.

Furthermore, Yu et al. (2022) found that the circular economy, alongside modern technologies, positively impacts supply chain and operational performance, which is consistent with this study’s emphasis on the importance of precise supply chain management and waste reduction in the automotive industry. Additionally, Sari et al. (2021) explored the role of sustainable lean production strategies in improving environmental and economic indicators, demonstrating that environmental metrics such as recycling and reduced energy consumption can significantly enhance production processes. These findings fully align with the present study’s focus on the influence of product design on recyclability and waste reduction. On the other hand, Sahoo’s (2020) findings regarding the role of leadership and organizational culture as critical factors in the success of lean production highlight the need for further examination of cultural and managerial dimensions in future research. This aspect was not directly addressed in the current study and could be considered a limitation.

Ultimately, domestic research such as that by Amin Tahmasebi and Zarepour (2022) has also demonstrated that the use of tools like Value Stream Mapping (VSM) can reduce production time and enhance productivity. In this regard, the present study suggests that tools such as VSM and lean management techniques should be examined in other industrial sectors to make the obtained results more generalizable. At the same time, one of the main limitations of the present study is its focus on a specific segment of the automotive industry in Iran, which may restrict the generalizability of the results to other industries or countries. While this research comprehensively examines various dimensions of product design, supply chain, and the use of advanced technologies, the influence of cultural, social, and environmental factors that may exist in different countries or other industries has not been fully considered. It is recommended that future research employ random sampling methods to enhance generalizability and conduct longitudinal analyses to assess the sustainability of impacts over different time periods. Additionally, investigating the effects of cultural factors and legal barriers in the implementation of new technologies could provide deeper insights.

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