IMPACT OF INDUSTRY (4.O) IN AUTOMOBILE INDUSTRY

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Abstract: The emergence of Industry 4.0, characterized by the fusion of cutting-edge technology and digitization, has significantly altered the automotive industry. Automation, data interchange, and digital technology are combined in Industry 4.0 to produce a more productive and adaptable production environment. This technological advancement is not without its difficulties, such as a call for improvement on cybersecurity to prevent online attacks, up skilling and reskilling of industry employees to ensure high level of competencies, to mention a few. The auto industry is moving toward a new paradigm of connected vehicles and intelligent mobility options outside of the production environment thanks to Industry 4.0. With the integration of (IoT) the Internet of Things, cars have become sophisticated devices that can gather, process, and communicate enormous amounts of data. Sensors placed throughout the vehicle provide real-time monitoring of performance, external conditions, and driver behaviour. This increases safety protections, maximizes fuel efficiency, and paves the road for preventative maintenance. This study aims at developing a workforce framework that will help increase organizational effectiveness within the industry 4.0 paradigm. It also provides recent views on the development of the automobile industry due to Industry 4.0 incorporation, the perceived and current difficulties and possible solutions to identified challenges.

1. Introduction

A new era of innovation and transformation has begun across many industries with the birth of Industry 4.0, and it is characterized by the digitization of industrial processes with cutting-edge technology integration.

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The automobile industry stands out among these industries as a notable winner and the driving force behind this technological revolution. The manufacture, operation, and user experiences of automobiles have undergone tremendous alteration due to Industry 4.0, which is based on the fundamental ideas of automation, connectivity, data analytics, and artificial intelligence [1].

The days of lone machines and labour-intensive manual production methods are passed. Modern intelligent factories using cutting-edge technology are revolutionizing the way business is done. Automation enabled by robotics and intelligent systems has changed production lines and increased accuracy, efficiency, and scalability. Assembling processes and material handling are seamlessly connected with machines that have sensors, actuators, and AI algorithms, speeding workflows and reducing human error [2]. With the development of telematics and vehicle-to-vehicle (V2V) communication technology, cars have integrated into a networked environment. Through seamless data sharing and communication, vehicles can convey vital information about traffic conditions, road dangers, and potential crashes, enabling pre-emptive safety measures and efficient traffic management [3] [4]. This connectivity has also changed how people travel and interact with cars because to the emergence of new mobility services like ride-sharing platforms and on-demand transportation. Usage of big data and advanced analytics is at the centre of Industry 4.0. The automotive business is no different, utilizing the power of data to uncover insightful information and promote well-informed choices. Manufacturers may enhance quality control, supply chain management, and demand forecasting by utilizing data from a variety of sources, including sensors, vehicle systems, and consumer interactions. By enabling preventive maintenance and prompt interventions, predictive analytics reduce downtime and improve overall operational efficiency.

Artificial intelligence (AI), which has become a vital enabler in the automobile sector, has hastened the development of smart manufacturing. AI algorithms power autonomous vehicles, enabling them to sense and comprehend their environment, make informed judgments, and navigate hazardous road conditions [5]. Driver assistance systems powered by artificial intelligence offer enhanced safety features including adaptive cruise control and collision avoidance. In the industrial industry, AI streamlines processes for resource allocation, predictive maintenance, and quality control. However, while the automotive sector seizes Industry 4.0's prospects, it also encounters fresh difficulties. Vehicles are becoming more connected, and a reliance on digital technology raises questions about cyber security flaws. Strong cyber security measures are important for the protection of sensitive data and maintenance of the safety of cars and their occupants in light of the potential of cyber-attacks and data breaches. To reduce the risks associated with connected automobiles, the industry must invest in strong encryption techniques, secure communication channels, and on-going monitoring [6].

1.1 Background of Study

The automotive sector has always been a pioneer in putting new technologies into practice to fulfil consumer needs. The sector has seen tremendous change as a result of Industry 4.0, which is defined by the convergence of digitization and cutting-edge technology. In order to create a more productive and adaptable manufacturing environment, Industry 4.0 combines automation, data exchange, and digital technologies [7].

Artificial intelligence is a significant driving force behind innovation in the automotive industry. According to [8]. AI algorithms power autonomous vehicles, allowing them to navigate hazardous road conditions, assess their surroundings, and make informed decisions. Driver assistance technologies powered by AI also increase safety and enhance the entire driving experience. AI also enhances industrial procedures, providing increases in operational effectiveness and predictive maintenance.

But putting Industry 4.0 technologies into practice also has its difficulties. As automobiles grow increasingly connected, cybersecurity becomes more important and calls for strong defences against online attacks [9]. Furthermore, the evolving technology environment necessitates a change in employee competencies, highlighting the necessity of upskilling and reskilling activities.

Industry experts, decision-makers, and researchers must comprehend how Industry 4.0 will affect the automobile sector. This study seeks to give a broad overview of Industry 4.0's revolutionary implications, spanning industrial procedures, linked cars, sophisticated analytics, artificial intelligence (AI), cybersecurity, and worker dynamics.

2 Literature Review

2.1 Review of the effect of industry 4.0 on Automobile industry

Bai *et al*. [10] reported that the fourth industrial revolution (IR4.0), which is centred on automation together with digitization, is the upcoming trend in automotive manufacturing systems. Government funding and support have undoubtedly accelerated this transition in the auto industry. The current study examines how industry 4.0 will impact the capabilities of supply and the practices of circular economy so as to enhance the performance of the firm. Employing a closed-ended survey, data across 286 respondents were obtained. The application of the techniques of circular economy leads to the increase in the operational and financial performance of the company. Industry 4.0 also has the capability to significantly enhance commercial operations. The empirical results are consistent with the notion that industry 4.0 positively affects supply chain effectiveness and also the adoption of circular economy principles. Furthermore, there is proof that the use of circular economy strategies improves both operational and financial results. Contrarily, operational performance improves the status of the economy, but supply chain competence has a favourable link with operational success but a weak correlation with economic performance. In order to achieve sustainable goals, the current research project provides recommendations to the participating businesses on how to incorporate industry 4.0 into manufacturing systems.

Bhatia and Kumar [11] also reported that Industry 4.0, was brought forth by novel and disruptive information as well as intelligence technologies. Production efficiency increases exponentially due to these novel technologies. They might also impact greatly on environmental and social sustainability. Organizations have to put into consideration the way Industry 4.0 technologies will affect sustainability. In this sense, the scientific or practitioner literature falls short of offering sufficient guidance. In this study, we investigate the sustainability effects and usability of the Industry 4.0 technology. A technique for evaluating sustainability based on the UN's SDG (Sustainable Development Goals) and which also takes into account a variety of social, economic, and environmental issues. In addition, a hybrid approach to multi-situation decision-making which incorporates VIKOR, hesitant fuzzy set and cumulative prospect theory was developed. This approach makes it possible to evaluate Industry 4.0 technology' performance and applicability effectively. To implement the method, we use secondary case data from WEF (World Economic Forum) research. Mobile technology, simulation, and drones, in that order, have the highest impact on sustainability

across all sectors from results obtained, with nanotechnology, mobile technology, and simulation having the greatest effects on sustainability with regard to the textile, apparel, as well as footwear factories. Recommendation is to implement Industry 4.0 technologies to have a greater effect on sustainability, though there is need for each technology to be evaluated carefully because it will affect the industry and also, it's sustainability in different ways. The correct goals and championing should be considered while investing in these technologies. Also, Industry 4.0 technologies include, cloud, simulation, additive manufacturing, artificial intelligence, big data analytics, blockchain and industrial internet of things but not limited to these mentions [11] [12].

2.2 Improvement and Industrial Sustainability

Verma and Venkatesan [12] also established that Industry 4.0 technologies have what it takes to greatly boost innovation as well as competitiveness and improve the industrial system's sustainability. In general, taking into account broader economic implications, efficient and reliable evaluation procedures and decision support systems can help manufacturing organizations understand and effectively apply such Industry 4.0 technologies [13]. Along with environmental and social issues, one of these more significant effects is enhancing the competitiveness of corporations and their nations. Industry 4.0 technologies exhibit high levels of unpredictability and variable performance results in real-world scenarios. Industry 4.0 can benefit manufacturing organizations in a number of ways, including improving working conditions, productivity, and quality. Businesses can be better understood and utilize Industry 4.0 technology with the aid of evaluation techniques. They could offer managerial decision-making assistance Early projects made use of various technologies and Industry 4.0 evaluation and appraisal techniques. AHP (analytical hierarchy technique) has been employed to assess barriers to Industry 4.0 initiatives for supply chain sustainability in evolving nations.

Raj *et al.* [14] opined that Industry 4.0 technologies are garnering relevance in the area of manufacturing as a result of the benefits they can provide, like increased productivity, lower costs, higher profits, etc. The relationships between the CSF and performance outcomes are also evaluated using regression analysis. "Data governance" is the component which the data demonstrate to be most crucial because of its influence on all four (4) performance outcomes which include (operational, product, economic, and responsiveness). Similar to this, "Legal aspects" have an impact on three out of the four performance outcomes, including operational performance, product performance, and economic performance. However, "collaboration and teamwork" impact efficiency and responsiveness in operations only. The report provides information on the factors necessary to meet performance targets for I4 technologies in the car manufacturing sector. The findings from the research can aid automakers choose wisely among the different strategies needed to successfully implement I4 technologies. Managers in firms can learn about methods that can be very helpful to implement and can help in obtaining desired results by understanding the links between CSF and performance characteristics. We recommend the study models in Figs. 1-4 in this regard. These models include "performance outcomes" as the dependent variable and "CSF to I4 implementation" as the independent variable. Utilizing I4 technology has many benefits, including operational performance improvement, improved economic performance, increased responsiveness, improved product performance among others. enhanced product responsiveness and performance. Nine CSF for adopting I4 technologies are also taken into consideration in this study.

Nine hypotheses that represent connections between CSF and outcomes of performance are put out for each model. Relationships between CSF and operational performance are denoted by H1a–H1i, those between CSF and product performance by H2a–H2i, those between CSF

and economic performance by H3a–H3i, and those between CSF and responsiveness by H4a–H4i.Regression analysis is used to investigate the associations between CSF and performance parameters.

Additionally, these interactions can be dependent on specific firm-level traits [88]. Business size is taken into account as a factor that may have an impact on the use of CSF and positively mitigate the connections between CSF and performance variables. This is due to the fact that larger firms are more likely to implement or concentrate on the elements and skills needed for I4 technologies and improve performance results. A s a result, there may be stronger connections between CSF and performance results compared to smaller enterprises, larger firms

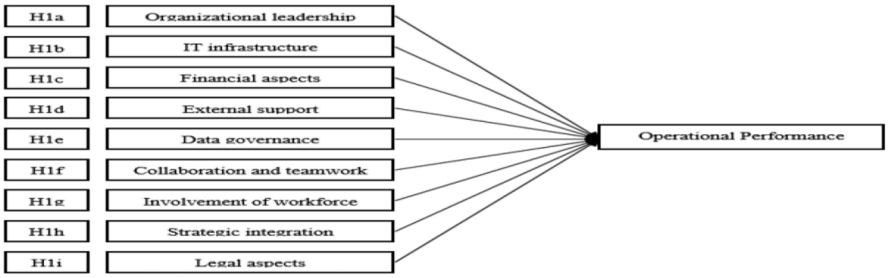


Figure 2.2.a. Relationship**s** between CSF and operational performance

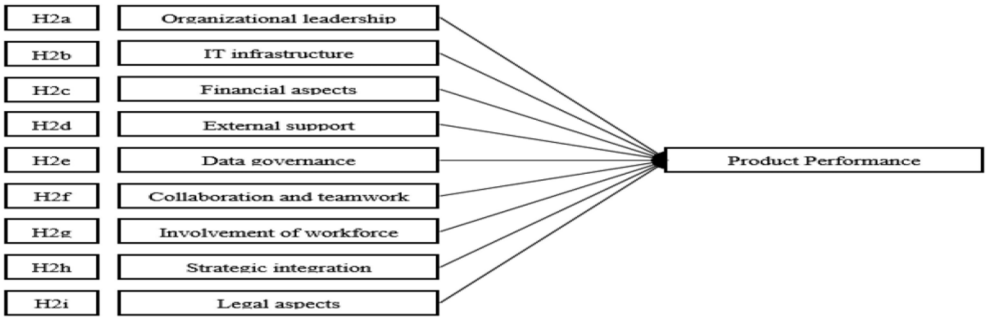


Figure 2.2.b. CSF and product performance relationships

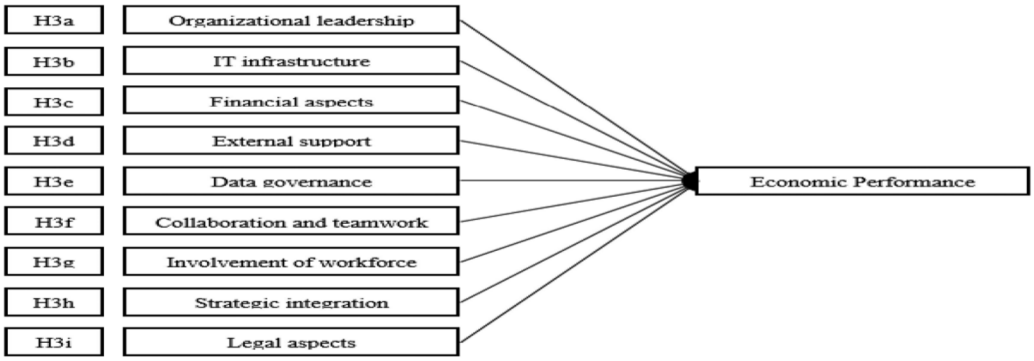


Figure 2.2.c connections between CSF and financial performance.

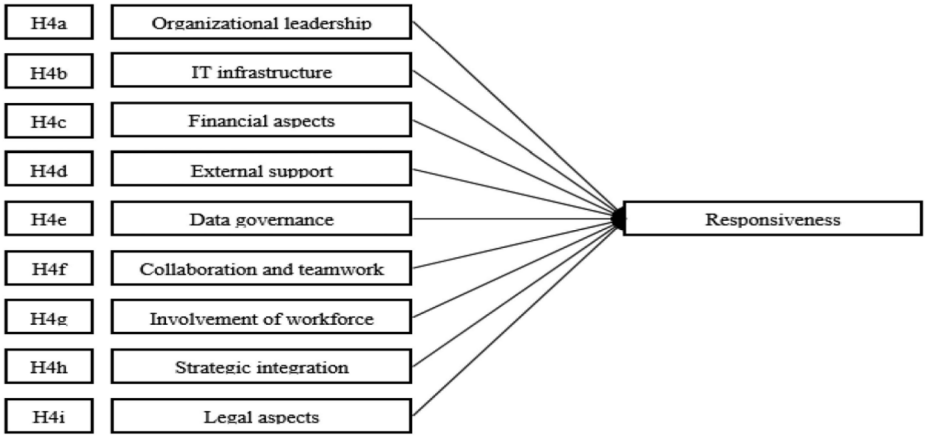


Figure. 2.2.d connections between responsiveness and CSF.

Ghadge et al. [15] Established that industry 4.0, which is propelled by significant advancements in manufacturing methods, will drastically alter the workforce and workplace. According to the study, there is a direct correlation between the Fourth Industrial Revolution and its consequences on the Indian automobile industry workforce. Effect of the Industry 4.0 paradigm on the function of HR professionals is also examined. The study's findings demonstrate that fruitful implementation is dependent on an organization's capability to captivate, keep, and grow its staff as well as to foster an atmosphere that values inventive and lasting learning through re-skilling and up-skilling The basis for this work was a comprehensive and critical survey of the literature on Industry 4.0 in addition to the automobile industry. Previous analyses of sector 4.0 implementation in the car sector concentrated mostly on technical areas and gave less attention to the effects on and initiatives for the workforce.

2.3 Productivity in the Automotive Industry

According to [14] [15], industry 4.0 is an innovative manufacturing concept which will increase the automotive sector productivity. Though, several barriers towards its application

exist in the Indian automotive sector context. The article establishes and analyzes the HRM (Human Resource Management) issues related to the deployment of Industry 4.0 in the Indian automobile sector employing a hybrid methodology. In this work, a hybrid model that combines the BMW (Best and Worst Model) and DEMATEL (Decision Making Trial and Evaluation Laboratory) is employed to assess the relative relevance of a variety of challenges before categorizing them into cause-and-effect groups. The study, which is unique and original, examines the most recent issues with HRM difficulties related to the adoption of Industry 4.0 methodologies regarding Indian automotive sector. Results obtained can be utilized by automakers in making judgments about how to address the underlying sources of problems of HRM in addition to promoting the best possible application of Industry 4.0 in their facilities. Industry 4.0 seeks to implement cutting-edge automation technology in manufacturing and process industries. The result is a leaner, more functional supply chain that would increase production by 45% to 55% [14]. It blends people, technology, and data. A paradigm shift from a conventional supply chain to a current supply chain is currently occurring in the industrial sector under the aegis of Industry 4.0. Industry 4.0 will, among other things, make it possible for mass product customization driven by information technology, to track raw materials and finished goods, to help with communication between raw materials, people, machines, and finished goods, to promote human-machine interplay, to build smart factories, and to develop new service and business figures. The automobile industry is India's largest industrial sector and a leading adopter of cutting-edge technologies. Additionally, the industry employs people with engineering credentials in fields like plastics, computer, chemical mechanical, electrical, structural, automotive electronics and communication among others. Additionally diversified are the skill sets and educational backgrounds of the workforce. In order to maintain sustainable operations in the current unpredictable business environment, organizations are looking into the usage of evolving technologies for decision-making and effective production planning. Industry 4.0 could help businesses by streamlining their operations. Academics and senior executives have so far mostly focused on technological issues rather than the challenges faced by the production industry workers located in countries like India which are developing. The obtained results will aid business HRM make the most use of the resources and expenses they are spending on adopting Industry 4.0. Additionally, the successful implementation of Industry 4.0 would result in significant cost reductions and increased organizational effectiveness. This study provides information on the topic at hand and leaves room for additional research.

The study by [15], offers evidence of the relationship between the two concepts, Industry 4.0 and GSCM (Green Supply Chain Management), based on experimental research done in the automobile sector. Using 243 responses obtained from automotive supply chain specialists across Europe (the UK inclusive), the hypothesized hypotheses are tested. To establish the relationship between Industry 4.0 technology, GSC practices and performance, an integrated, two-stage method combining structural equation modeling and interpretive structural modeling is used to produce a multi-level hierarchical structure. The study found a stronger connection between Industry 4.0 and GSC practices in the automotive supply chains than between Industry 4.0 and direct GSC practices, which had a direct impact on GSC performance. Future supply chains should concentrate on developing and connecting technologies like IoT, Cyber-Physical Systems (CPS) including Blockchain for the efficient adoption of Green Supply Chain principles. Disruptive technologies have a big impact on Green Supply Chain practices, especially reverse logistics and green buying, which are crucial for boosting GSC performance [15]. Businesses will gain from recognising and integrating key Industry 4.0 technology with GSC practices in order to increase sustainability performance. Major automotive manufacturers have recently incorporated a number of digital technologies, including IoT, AI, and CPS, in autonomous vehicles. Additionally, worldwide automobile sectors together with their supply chains are constantly under pressure

to keep tight environmental regulations without sacrificing innovation and technological advancements. Industry 4.0 technologies, such as 3D printing, robots, and also AI, can enhance the effectiveness of product design, production, as well as supply chains. It might be argued that Industry 4.0 technologies influence the adoption of GSC practices in the automobile factory, which has a direct impact on the performance supply chain. A fresh perspective on business and the technologies it employs, Industry 4.0 supports businesses in their transition to sustainable development.

2.4 Automated Manufacturing

Papulová et al. [16] conducted a study on automated manufacturing in the automobile factory with a focus on technology associated with Industry 4.0. Discussion on how industrial companies are utilizing specific Industry 4.0 technologies like cutting-edge robotics, 3D printing, IoT, or automated manufacturing were made. Research sample comprises manufacturing companies in the automobile industry with operations in Slovakia and the Czech Republic. The two nations are major players on the international auto manufacturing sector. An electronic questionnaire to gather the data was created, and questions based on a theoretical analysis of earlier studies and research were developed. Two presumptions were made, and their validity was checked by measuring the typical amount of technology used. How far automation technologies and other Industry 4.0 technologies have been adopted were looked into. The findings revealed widespread use of industrial robots, programmable devices like PLCs, and sensors. Automotive automation technologies are consistently progressing. Recently, obstacles and opportunities associated with Industry 4.0 that are advancing automobile sector significantly right from the 1st industrial revolution [16]. The 1960s of the 18th century are when the industrial revolution really got going. The first industrial revolution was marked by the adoption of a novel energy source, the steam engine. The second industrial revolution boosted production, the use of assembly lines, and electricity after its discovery. The third industrial revolution was brought about by computer technologies like computers and PLC programmable devices. During the fourth industrial revolution, manufacturing companies are introduced to advanced robotic technology, 3D printing, IoT, or automated production.

2.5 Benefits of Industry 4.0 application idea in Manufacturing Firms

Instruments for tracking and forecasting: Strong monitoring technologies that help with the early identification of issues or system failures fit us perfectly within the context of the Industry 4.0 concept. By utilizing Industry 4.0 technology, many models of the manufactured goods can be produced at the same time on a single line while keeping the desired order. There is technology flexibility in network. The entire production process becomes more dynamic and compatible as a result. Obviously, while speaking outside of the organization, follow the necessary security guidelines Both the vertical level (across organizational departments) and also the horizontal level (supplier-company-customer) of the supply chain should be digitalized [17].

The development of Industry 4.0-based manufacturing systems in the automobile sector, specifically in the context of Slovakia, is the major topic of the study. The analysis of how these cutting-edge business performance-enhancing technologies, such as remote sensing data fusion, computer vision algorithms methods including mapping and navigation tools, might improve sustainability in the Slovak automobile sector is the goal.

The research offers light on the possible advantages and implications for sustainable business performance by looking at the way these cutting-edge technologies are utilized in the automotive industry. It underscores the need of utilizing these technologies to be competitive in the world market while highlighting the role of Industry 4.0 in fostering innovation and

digitalization in the automobile sector. In general, the study advances knowledge of how production systems built on Industry 4.0 might be used in the automobile sector, specifically in the Slovak setting. It emphasizes the revolutionary potential of these technologies as well as the importance of their contribution to improving sustainable company performance, reshaping the domestic economy, and influencing shifts in global value chains. [18].
The framework covers smart working and smart supply chains in addition to smart manufacturing and smart goods for processing. In order to provide real-time visibility, optimization, and agility in logistics and distribution processes, digital technology and data analytics are integrated throughout the supply chain. This is known as a "smart supply chain." It entails utilizing technologies like IoT, RFID, cloud computing, and analytics to increase the traceability, responsiveness, and efficiency of the supply chain [19].

2.6 Industry 4.0 on industrial employment

Beier [20] in their study, compared the opinions of practitioners from Brazil, China, and Germany to determine how Industry 4.0 would affect industrial jobs. Given the varied situations and circumstances in many nations, it acknowledges the necessity for empirical evidence in understanding the impact of Industry 4.0 on industrial employment.

The research attempts to offer insights into the future view of industrial practitioners in various regions while taking into account the variability of industrial development and technology adoption between nations. To fully grasp the ramifications, it also takes into account variances across various industrial sectors and firm sizes. By examining practitioners' perceptions, the work focuses on shedding light on the way Industry 4.0 will influence staffing requirements in various domains. This analysis helps to uncover the nuanced differences in the impact of Industry 4.0 on industrial employment, providing valuable insights for policymakers, industry leaders, and researchers [20].

Overall, the work adds to the existing knowledge by making available experimental evidence and comparative analysis of practitioners' perceptions from Germany, Brazil in addition to China, highlighting the diverse consequences of Industry 4.0 on industrial employment across different contexts and sectors. By implementing battery swapping, EV users would have access to a fresh and fully charged battery whenever needed, eliminating the time-consuming charging process. This approach could potentially increase the driving range and reduce the overall downtime of EVs, making them more practical and convenient for users. Additionally, the study mentions the possibility of producing modular batteries on-site at the battery stations. This approach could further enhance the efficiency of battery swapping by ensuring a constant supply of batteries and reducing the need for transporting and storing large quantities of batteries.

By exploring this alternative approach, the study aims to add to the present research efforts in the electric mobility sector. While increasing battery performance and reducing charging time remain important areas of focus, battery swapping presents a unique solution that could address the range limitations of electric vehicles and improve the overall user experience. Deeper research and development in this aspect, could lead to progress in electric vehicle technology and contribute to the movement to a more environmentally friendly and sustainable transportation system. The utilization of existing gas station networks for battery replacement in electric vehicles is an interesting concept that can potentially address the time-consuming charging process. By repurposing gas stations as battery swapping stations, EV users would have the convenience of quickly replacing their depleted batteries with fully charged ones, similar to how traditional vehicles refuel with gasoline.

To facilitate the implementation of this concept and address the associated challenges, the absorption of Industry 4.0 Key enabling Technologies is proposed. Industry 4.0 technologies, such as data analytics, IoT and cloud computing can be leveraged to create a holistic framework for efficient battery swapping operations.

This framework would encompass various aspects, including the design of the electric vehicle itself to support context-awareness, ensuring compatibility between the vehicle and the battery swapping infrastructure. Additionally, the mechanical mounting of batteries is discussed as a specific solution, implying the development of standardized and easily replaceable battery modules that can be seamlessly integrated into the vehicle's structure.

By applying Industry 4.0 technologies and adopting a holistic framework, the challenges associated with battery swapping, such as logistics, compatibility, and seamless integration, can be effectively addressed. This approach has the potential to enhance the practicality and usability of electric vehicles by significantly reducing the charging time and increasing the driving range.

Further research and development in this area, along with collaboration between automotive manufacturers, infrastructure providers, and other stakeholders, will be crucial for realizing the vision of using gas station networks for battery replacement and advancing the adoption of electric vehicles as a sustainable transportation solution.

3 Research Methodology

The research methodology of this study involves examining the interplay between Industry 4.0 (I4.0) with the challenges faced by Electric Vehicles (EVs). The focus is on understanding how I4.0 solutions can effectively address the challenges related to the infrastructure of the battery replacement stations and the EVs themselves. Figure 3.0: Link between Industry 4.0 and Electric Vehicle (EV) Challenges

The challenges associated with the infrastructure of the replacement battery stations and the EVs are categorized into three main areas: safety, operational, and connectivity issues. These challenges are identified and analysed to get a thorough understanding of the obstacles that need to be overcome for the successful implementation of battery swapping networks [21].

To address these challenges, the study explores potential I4.0 solutions. Industry 4.0 technologies, such as IoT, data analytics, cloud computing and also artificial intelligence are investigated to determine their suitability in resolving the identified issues. The aim is to find I4.0 solutions that can make sure that there is effective safe operation and distribution of the battery replacement stations network.

By examining the connection between I4.0 and EV difficulties, the study seeks to identify and propose feasible strategies and technologies that can mitigate the identified safety, operational, and connectivity issues. The ultimate goal is to establish a robust and reliable infrastructure for battery swapping stations that can facilitate the widespread adoption of EVs and address the limitations associated with charging time and driving range.

The research methodology employed in this study involves a thorough analysis of the challenges, an exploration of potential I4.0 solutions, and an evaluation of their applicability in the context of the EV ecosystem. This approach gives room for a systematic assessment of the key elements and considerations necessary for the effectual integration of I4.0 technologies in the EV industry [22].

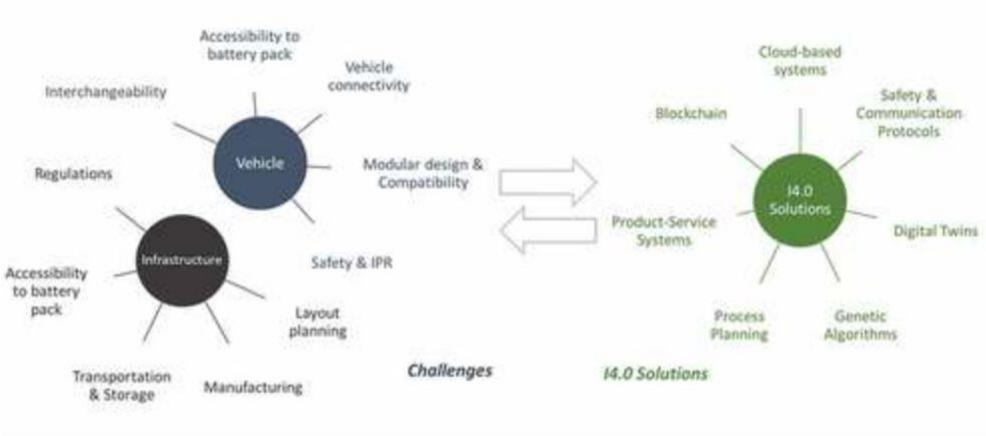


Figure 3. Research methodology profile

3.1 Role of Machine Vision (MV)

3.1.1 Role of Machine Vision (MV)

Javaid [23] opined that machine Vision (MV) plays a very vital role in the adoption of Industry 4.0 by leveraging digital technologies. Its ability to process large volumes of visual data enables quick detection and identification of faulty goods and defects, allowing for timely interventions in manufacturing processes. MV versions are vital for achieving efficient production and find utilization in inventory management, quality assurance and enforcement. By minimizing human error, MV contributes to reducing the likelihood of mistakes and improving overall productivity.

This work offers a brief summary of MV and its relevance to Industry 4.0. It highlights the combined characteristics and smart technologies of machine vision that enhance the capabilities of Industry 4.0 systems. The authors present a diagrammatic representation of these features and technologies to illustrate their integration within the framework of Industry 4.0.

Additionally, the paper pinpoints and explains important applications of MV in the context of Industry 4.0. These applications encompass various stages of the manufacturing process, as well as inventory control and supply chain management. Each application represents a unique and innovative approach to handle the requirements of Industry 4.0 as well as the digital transformation of the industrial sector.

In the period of Industry 4.0, where digital technologies are reshaping production and industrial techniques, MV plays a pivotal role. Its ability to analyse visual data and enable real-time decision-making contributes to increased efficiency, productivity, and quality control. The paper lays emphasis on the significance of adopting MV in the context of Industry 4.0 and highlights its diverse applications across different domains of the digital industry transition. Indeed, the development of Machine Vision (MV) systems capable of surpassing human capabilities in terms of accuracy and perception opens up numerous opportunities in dynamic systems. By enhancing robots' ability to perceive and interact with their environment, MV enables collaboration between humans and machines in various applications [23].

In the smart plant of the future, machine vision assumes a crucial part. Automated manufacturing lines equipped with MV systems have the capability to adapt and optimize their operations in real-time. By continuously monitoring and analyzing visual data, MV systems can identify bottlenecks, detect anomalies, and make adjustments to optimize productivity, performance, and profitability. This adaptability and optimization potential contribute to the concept of a smart plant that operates efficiently and effectively in response to changing conditions. The integration of MV in the smart plant enables a range of benefits. These include enhanced quality control through real-time defect detection and sorting, improved process efficiency through automation and optimization, reduced downtime and maintenance costs through predictive maintenance capabilities, and increased worker safety through the identification of potential hazards. Moreover, MV facilitates the implementation of advanced technologies like robotics, AI in addition to data analytics. By providing accurate and reliable visual data, MV systems contribute to the decision-making process, enabling intelligent systems to perform tasks that were previously limited to human operators. Overall, the integration of MV in the smart plant of the future offers important potential for optimizing production processes, improving performance, and driving profitability. It empowers automated systems to adapt and respond to dynamic conditions, paving the way for improved productivity, efficiency, and competitiveness in the production industry. Industry 4.0, with its integration of advanced technologies together with data-driven approaches, has the ability to bring significant sustainability benefits to manufacturing processes. Here are some ways in which Industry 4.0 adds to enhancing sustainability [24]. Resource Efficiency: Industry 4.0 makes possible real-time monitoring and optimization of resource usage, like energy, water, and raw materials. Smart sensors and connected devices provide data on consumption patterns, allowing for efficient allocation and reduction of waste.

Pollution Reduction: By implementing intelligent monitoring and control systems, Industry 4.0 can help minimize pollution and emissions. Real-time data analysis allows for proactive identification of potential environmental hazards and enables prompt corrective actions.

Energy Management: Industry 4.0 technologies enable intelligent energy management systems that optimize energy consumption, reduce energy waste, and support the integration of renewable energy sources. This leads to reduced greenhouse gas emissions and a more sustainable energy footprint. Product Lifecycle Management: Industry 4.0 facilitates improved product lifecycle management, including product design, manufacturing, use, and disposal. Through data integration and analytics, companies can optimize product designs for sustainability, extend product lifetimes, and enable efficient recycling and disposal processes. Predictive Maintenance: By leveraging advanced analytics and IoT. Industry 4.0 enables predictive maintenance, minimizing downtime and reducing the need for unplanned repairs. This leads to more efficient use of resources and extends the lifespan of equipment and machinery.

Supply Chain Optimization: Industry 4.0 technologies improve supply chain visibility with transparency, enabling better coordination and optimization of logistics operations. This leads to reduced transportation emissions, lower inventory levels, and improved overall supply chain efficiency. Industry 4.0 can promote smart packaging options that cut down on material waste and make recycling more effective. Smart packaging also helps with waste management. Additionally, by increasing recycling rates and lowering landfill waste, networked systems can improve waste management procedures [25]. Overall, industrial facilities may make data-driven decisions that increase sustainability, lessen environmental impact, and increase operational efficiency because to Industry 4.0's ability to collect and also analyze data obtained from numerous devices and sensors. Companies can attain a more sustainable and environmentally friendly approach to production by utilizing technology to construct smart plants.

3.2 Industry 4.0 Technologies and OHS (Occupational Health and Safety)

The study by [26] is significant as it gives a deeper insight on the relationship between the adoption of Industry 4.0 technologies and their influence on OHS. Here are some key points that are based on the findings: Increasing Interest: The research indicates that there is a growing interest among researchers in investigating the effects of Industry 4.0 technologies on OHS. This suggests a recognition of the importance of understanding and addressing the potential OHS implications of these technologies.

Limited Empirical Studies: The study highlights the limited number of empirical studies available on this topic. This indicates that more research and empirical evidence are needed to fully understand the specific associations between the implementation of Industry 4.0 technologies with their effect on OHS. Main Sectors Identified: Despite the limited empirical studies, the study identifies the main sectors that apply Industry 4.0 technologies and have potential effects on OHS. This information can help target further research and intervention efforts to these sectors, focusing on understanding and addressing OHS challenges specific to these industries.

Regional Focus: The study mentions that the research on this topic is mostly conducted in Europe, indicating a regional focus on understanding the relationship between Industry 4.0 technologies and OHS. It would be valuable to explore this topic in other regions as well to capture a more comprehensive understanding of the global implications. In summary, the study highlights the importance of further research and practical evidence on the associations between the adoption of Industry 4.0 technologies and their influences on OHS. By identifying the main sectors involved and recognizing the increasing interest in this area, the work gives very relevant comprehension and insights specially for researchers, policymakers, and industry practitioners to address the OHS implications of Industry 4.0 technologies.

3.3 Automotive Industry and Digital Transformation

Tóth-Kaszás et al. [27] aimed to assess the readiness of automobile industry key players in Hungary regarding the digital transformation. The study focused on various dimensions of the digital transition, including products/services, supply chain, strategy and leadership, business processes, human resources and manufacturing. Company leaders were interviewed to gather information on their progress, challenges, potential human resource management responses. Opportunities and organizational culture. Based on the findings, the assessed Hungarian automobile industry players were classified into groups. This classification likely aimed to group companies based on their level of digital transformation readiness or their approaches to implementing digital technologies and processes. By categorizing the companies into clusters, the researchers could identify common characteristics, challenges, and potential areas for improvement within each group.

The obtained results of this research provide valuable and deeper understanding of the current state of digital transformation within the Hungarian automotive industry. It allows researchers, industry professionals, and policymakers to understand the digital readiness of automotive actors and identify areas that require attention and improvement. This information can help guide strategic decision-making, resource allocation, and the development of supportive policies to facilitate a successful digital transition within the automotive sector.

Ericsson et al. [28] conducted interviews with representatives from 24 SME (small and medium-sized enterprise) suppliers in Sweden automotive industry. The goal was to understand the role of Industry 4.0 (I4.0) technologies in the strategic work of these firms. The results/findings indicate that these SME suppliers do not currently consider the initiation of I4.0 technologies in their production as part of their strategic planning.

This suggests that the SME suppliers in the automotive sector may not know the potential gains and implications of I4.0 technologies or also may not perceive them as strategically important for their businesses. It highlights a gap between the potential of I4.0 technologies and the strategic decision-making processes of these firms. The lack of consideration for I4.0 technologies in their strategic work may limit their ability to leverage the advantages offered by these technologies, such as increased efficiency, productivity, and competitiveness.

The study's findings underscore the importance of raising awareness among SME suppliers in the automotive industry about the potential benefits and strategic implications of I4.0 technologies. It suggests the need for further research and initiatives to support these firms in understanding and integrating I4.0 technologies into their strategic planning processes. By doing so, SME suppliers can enhance their ability to adapt to the changing automotive industry landscape and stay competitive in the face of evolving customer demands and market dynamics.

The study highlights a significant finding that automobile SME suppliers in Sweden do not consider I4.0 technologies or any other lasting enhancement programs in their strategic planning for production. This finding is noteworthy as it contradicts recommendations from previous studies that emphasize the significance of I4.0 technologies for the future competitiveness of automotive SME suppliers.

Taking the position to be the first to experimentally investigate the function of production in the strategic work of these firms, the study contributes valuable insights to the deliberation on how automotive SME suppliers can strategically utilize I4.0 technologies in their manufacturing processes. The findings suggest that there is a gap between the potential gains of I4.0 technologies and the strategic decision-making processes of these firms. The study's results underscore the need for increased awareness and understanding among automotive SME suppliers about the strategic value of I4.0 technologies in manufacturing. It also emphasizes the importance of incorporating long-term improvement programs, including I4.0 technologies, into the strategic planning of these firms. By doing so, automotive SM E suppliers can enhance their competitiveness, improve efficiency, and adapt to the changing demands of the automotive industry [28].

Overall, the study sheds light on the current state of strategic planning among automotive SME suppliers and provides valuable insights for practitioners, policymakers, and researchers interested in the assimilation of I4.0 technologies in the automotive sector. Further research and initiatives can build upon these findings to develop guidelines and support mechanisms that enable automotive SME suppliers to strategically leverage I4.0 technologies in their production processes.

3.4 Industry 4.0 and labor/Workforce

Carey and Mordue [29] in their study, shows that the post-2000 period has seen a shift in the automotive manufacturing landscape, with low-cost labor countries emerging as significant hubs for production. However, this shift has also led to challenges for automotive semi-periphery countries, which have struggled to preserve vehicle manufacturing and gain directive for more knowledge-intensive areas of the automotive value chain. In this context, Industry 4.0 (I4.0) is seen as the standard tool to enhance competitiveness for these countries.

Despite having higher labor costs and lacking a domestic automaker, automotive semi-periphery countries possess well-educated workforces. Industry 4.0 technologies offer opportunities for these countries to leverage their skilled workforce and improve their competitiveness in the automotive industry. By adopting advanced digital technologies, automation, and data analytics, these countries can enhance their manufacturing processes, increase in productivity and cost reduction. Industry 4.0 enables the consolidation IoT, cyber-physical systems, and advanced data analytics to design smart factories and supply chains. This allows for greater flexibility, customization, and efficiency in production processes. Automotive semi-periphery countries can leverage these technologies to optimize their manufacturing operations, improve product quality, and satisfy the demands of a market that is changing rapidly. Furthermore, Industry 4.0 reveals opportunities for these countries to participate in higher value-added activities in the automotive value chain. By embracing technologies additive manufacturing, AI and robotics they can expand their capabilities beyond traditional assembly and manufacturing tasks. This can include areas such as research and development, design, engineering, and advanced component manufacturing [30].

In summary, Industry 4.0 offers automotive semi-periphery countries a pathway to enhance their competitiveness in the global automotive industry. By leveraging their well-educated workforce and adopting advanced digital technologies, these countries can overcome the challenges posed by low-cost labor countries and position themselves as knowledge-intensive players in the automotive value chain. However, it is very important for these countries to invest in the necessary infrastructure, skills development, and supportive policies to harness fully, the Industry 4.0 potential [31].

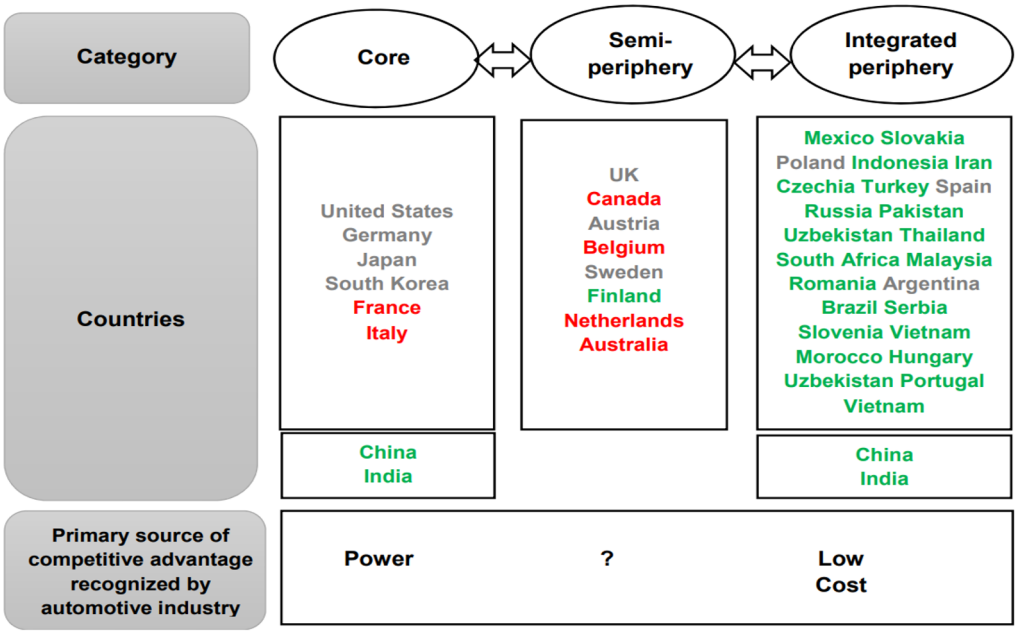
4. Global Automobile Industry and it's Advancement

The global automobile industry has experienced uneven development and territorial restructuring, leading to the categorization of automotive producing jurisdictions into three types: the core, semi-periphery, and integrated periphery. These categories are based on factors such as the presence of a domestic original equipment manufacturer (OEM), characteristics of the supplier sector, and the cost of local labor. Each category has its own set of territorial assets that influence the effectiveness of policies implemented by stakeholders in those regions.

However, for automotive semi-periphery regions, the advancement of public policies necessary for development becomes particularly challenging due to the lack of a clear-cut competitive advantage in either manufacturing or innovation n. These regions may not have a domestic OEM or may face higher labor costs, making it difficult to attract investments and develop a strong automotive industry presence.

In such circumstances, policymakers in automotive semi-periphery regions need to carefully consider their strategic approach to foster development. They may need to focus on alternative strategies such as creating favorable business environments, supporting innovation and research and development, promoting collaboration between industry and academia, and leveraging niche market segments where they can establish a competitive edge [32]. While these regions may not possess the same level of competitiveness as the core automotive jurisdictions, they can still find opportunities for growth and development by capitalizing on their unique strengths and assets. By implementing targeted policies and initiatives, these regions can create an environment that supports investment, innovation, and the advancement of their automotive sector. In conclusion, lack of a clear-cut competitive advantage in manufacturing or innovation poses challenges for policymakers in automotive semi-periphery regions. However, by adopting strategic approaches that leverage their territorial assets and focus on alternative development strategies, these regions can still foster

growth and compete within the global automotive industry. Figure 4.0 captures key factors influencing those developments. It also encompasses broader attributes of each stratum.



Key Attributes			
Homegrown automakers	Yes	No	No
Automotive R&D spending	High	Low – Medium	None – Low
Labour costs	High	High	Low - Medium
Foreign ownership	Low – Medium	Medium – High	High
Homegrown Top 100 Suppliers	High	Low – Medium	None – low

Legend

Green font	denotes production increase of 33% or greater between 2000 and 2019
Red font	denotes production decrease of 33% or greater between 2000 and 2019
Gray font	denotes production within 33% (up or down) of 2000 level in 2019

Source: Framework adapted from Pavlinek (2018) and Mordue and Sweeney (2020b)

Figure 4.0: Framework for categorizing the largest auto producing nation Source:[33].

4.1 Applications of the latest Developments

Qazi et al. [34] focused on the latest developments in technologies related to Industry 4.0 and their potential applications in various fields, particularly in the automation industry. It acknowledges that Industry 4.0 brings the concept of smart industries, with intelligent materials, designs, and faster data transmission playing crucial roles in shaping the

advancements. It also highlights that constant efforts are being made to develop new and smart materials with diverse applications. However, they also acknowledge that despite their appeal, these technologies face challenges when it comes to mainstream adoption by consumers. The paper aims to discuss these technologies in detail, explore their potential applications in different sectors, and provide practical insights on how to facilitate their integration into the automation industry. Therefore, it has the goal of contributing to the understanding of the latest advancement s and their implications for various fields.

Automation involves employing technology with machinery to carry out processes with the least human effort. It aims to streamline and optimize operations by reducing the need for manual labor and increasing efficiency. Automation is obtainable in different industries and sectors, manufacturing inclusive, also logistics, healthcare, and even everyday devices with appliances. It enables processes to be carried out more accurately, quickly, and consistently, often resulting in improved productivity, reduced errors, and enhanced safety [35].

Industry 4.0, builds upon the advancements of the previous revolutions and focuses on the convergence of IoT, digital technologies and physical systems. It involves the integration of IoT, clou computing, AI, cyber-physical systems and big data analytics to create smart and interconnected manufacturing environments. In Industry 4.0, machines, products, and systems communicate and cooperate with each other through the IoT. This enables real-time data collection, analysis as well as decision-making, which lead to more efficient and flexible production techniques, improved quality control, and the ability to customize products according to individual customer needs. The ultimate goal is to create highly adaptable, intelligent, and interconnected manufacturing systems that can optimize performance, reduce costs, and enhance overall productivity [36].

4.2 Revolutionization of Industry 4.0

Industry 4.0 has the ability to revolutionize various industries and sectors, including manufacturing, logistics, healthcare, and transportation, among others. It represents a new era of technological advancements and opportunities for businesses to innovate, optimize operations, and create new value. that the person has access to a smart system equipped with artificial intelligence analytics and big data. The system can analyse the virtual space, identify the brown cubes of small dimension, and provide the person with the necessary information to locate and retrieve them quickly. This is an example of how big data and AI analytics can help in managing and making sense of vast amounts of data in real-time, enabling efficient decision-making and problem-solving in Industry 4.0.[37]. IoT and connectivity: In Industry 4.0, machines, devices, and sensors are interconnected through the Internet of Things. They can communicate, share data, and collaborate together autonomously. This connectivity ensures real-time monitoring, control, and optimization of industrial processes. For example, sensors embedded in manufacturing equipment can collect data on performance, temperature, and maintenance needs, which can then be analysed to predict and prevent potential issues or optimize production efficiency. Additive manufacturing (3D printing): Additive manufacturing, commonly called 3D printing, is a key technology in Industry 4.0. It allows for the creation of 3D objects by adding layers of material based on a digital model. Additive manufacturing enables customization, flexibility and rapid prototyping capabilities. It makes possible the manufacturing of complex and customized parts on-demand, reducing lead times and costs associated with traditional manufacturing methods. Cloud computing and edge computing: these play important roles in Industry 4.0. Cloud computing guarantees the storage, processing, including analysis of large amounts of data in centralized cloud servers, providing scalability and accessibility to businesses. Edge computing, on the other hand, involves processing data locally on edge devices or gateways, closer to the source of data

generation. It enables real-time decision-making and reduces latency by processing critical data locally, enhancing the responsiveness and efficiency of industrial processes. These pillars of Industry 4.0 represent the integration of advanced technologies and concepts to transform traditional industries and enable more efficient, intelligent, and connected manufacturing systems. Electric motors operate more quietly than internal combustion engines, leading to reduced noise pollution. This is especially beneficial in urban areas, where noise levels can have a notable effect on the quality of life. The integration of EVs can lead to the development of a diverse charging infrastructure, including home charging stations, workplace charging, and public charging stations. This provides flexibility and convenience to EV owners, allowing them to charge their vehicles at various locations and adapt to their specific needs. EVs are at the forefront of technological advancements, incorporating features such as regenerative braking, advanced battery management systems, and connectivity options. These advancements not only enhance the driving experience but also contribute to the overall progress of the automotive industry.

Tripathi [38] developed methodology for cleaner production management employing lean and smart manufacturing in Industry 4.0 aims to improve productivity while considering sustainability and environmental factors. The methodology incorporates various approaches and technologies to optimize operations and address matters like product quality alongside worker safety. Key components of the methodology include: Lean principles are applied to eliminate waste, improve process efficiency, and streamline processes. Techniques which include 5S methodology, value stream mapping, and just-in-time production are utilized to optimize production processes. Smart manufacturing involves the integration of digital technologies and data analytics to enhance decision-making and overall production efficiency. IoT, Cyber-physical systems and artificial intelligence are utilized to enable real-time monitoring, predictive maintenance, and intelligent automation. The methodology incorporates sustainable production planning models to ensure that productivity improvements are achieved while considering resource limitations, minimizing waste generation and environmental impacts. This includes optimizing resource utilization, reducing energy consumption, and implementing environmentally friendly practices. Cleaner shop floor environmental management: The methodology focuses on improving environmental management within the shop floor by implementing measures to reduce emissions, control pollutants, and enhance waste management. This includes the adoption of green technologies, efficient resource usage, and adherence to environmental regulations [38]. The developed methodology is validated through case study examination in the automobile manufacturing industry together with a mining machinery assembly unit. The case studies demonstrate the effectiveness of the methodology in enhancing productivity while addressing environmental concerns and resource constraints. By integrating lean and smart manufacturing principles, along with sustainable production planning models, the methodology contributes to achieving cleaner and more efficient production systems in the context of Industry 4.0. It presents a structure/framework for organizations to optimize their operations, improve productivity, and align with sustainable and environmentally responsible practices.

5 Conclusion

Lastly, the workforce and skills needed in the car sector must also change as a result of the deployment of sector 4.0 technologies. Job responsibilities may change as a result of the integration of automation and AI, necessitating a move towards more specialized technical skills like data analysis, programming, and system integration. In order to empower the

workforce during this transformation, upskilling and reskilling efforts are becoming increasingly important.
The results obtained from the study indicate that the developed methodology for cleaner production management employing lean and smart manufacturing in Industry 4.0 is effective in providing a sustainable production system and addressing shop floor management challenges. It enables organizations to improve productivity within checked constraints and offers solutions to common challenges experienced in shop floor management.

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