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Integration between Mechanical Engineering and Robotic Process Automation: A Way to Foster Sustainable Business Operations

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ABSTRACT

The integration of mechanical engineering and robotic process automation (RPA) has become increasingly important for improving organizational efficiency and achieving sustainable business operations. However, limited research has examined how engineering capabilities contribute to sustainability through both the positive and negative consequences of automation. This study investigates the direct effect of mechanical engineering on sustainable business operations and examines the mediating roles of cost reduction and operational efficiency, quality improvement, and robotization disadvantage. A quantitative, cross-sectional research design was employed, and data were collected from 202 employees working in the automotive manufacturing industry using a structured questionnaire. The findings reveal that mechanical engineering significantly enhances sustainable business operations while positively influencing cost reduction and operational efficiency, quality improvement, and robotization disadvantage. Furthermore, cost reduction and operational efficiency together with quality improvement positively affect sustainable business operations, whereas robotization disadvantage exerts a significant negative effect. Mediation analysis confirms that all three variables significantly transmit the influence of mechanical engineering on sustainable business operations. The study extends the Resource-Based View by demonstrating how engineering capabilities create sustainable organizational value through multiple operational mechanisms. The findings provide valuable managerial insights for organizations seeking to balance automation benefits with sustainable operational performance.

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1. Introduction

The rapid advancement of digital technologies has fundamentally transformed the way organizations design, manage, and optimize their business operations (Katalla & Masele, 2026). In this technological advancement, one of the most effective solutions is robotic process automation (RPA) (Parakala, 2026). RPA has the potential to transform the industry by automating repetitive, rule-based, and time-consuming processes, thereby enhancing operational efficiency and cutting down on human effort and expenses (Afriliana & Ramadhan, 2022; Moderno et al., 2024). Mechanical engineering, meanwhile, remains an important discipline in improving the productivity of industry by designing, developing, optimizing, and maintaining engineering systems that improve manufacturing productivity and organizational performance. As mechanical engineering concepts get closer and closer to intelligent automation, organisations have the potential to achieve sustainable business operations through improved operational efficiency, better process quality and optimising the use of resources (Borisov & Yakovlev, 2020). Digital transformation is a key change that continues in industries, and understanding the complementarity of the mechanical engineering capabilities with RPA has become an important research priority.

Sustainable business operations have become a strategic objective for organizations seeking to balance economic performance with efficient resource utilization and long-term competitiveness (Agrawal et al., 2022). In order to improve productivity, businesses are being expected to reduce their operational waste, avoid unnecessary expenditure and ensure products and services are of the same quality. These expectations have fueled investments in automation technology that not only boosts the efficiency of an organization, but also helps to promote sustainable operational practices (Panyaram & Kotte, 2025). While RPA has shown to be very effective in improving administrative and operational workflows, its ability is largely reliant on the engineering skill set required to design processes, connect systems, optimize equipment and standardize workflows. Therefore, mechanical engineering forms the technical basis for automation technologies to create and add value to the organization in a sustainable way.

Although a lot of automation technologies have been adopted in various industries such as manufacturing and service (Chirumalla et al., 2024), previous research has mainly been limited to mechanical engineering and robotic process automation as a separate research area (Dudukalov et al., 2021; Schlund & Schmidt, 2021; Świder et al., 2006). While research into mechanical engineering is mostly technical innovation, product development, manufacturing processes, and engineering education, research into RPA is mostly software automation, process digitization, operational efficiency, and implementation challenges. There have been comparatively fewer studies that have explored how mechanical engineering skills enable the successful deployment of RPA to make business operations more sustainable. Furthermore, the previous literature has mostly analyzed the positive effect of automation and failed to consider how engineering attributes affect sustainability.

Another key constraint in the existing literature is the multidimensional impacts of RPA. In most of the previous studies, the focus was placed on positive organizational outcomes including cost savings, improvements in productivity, operational efficiency, and increase in service quality (Panyaram & Kotte, 2025; Parakala, 2026). But other effects of automation adoption are also negative for the organization, such as more formal procedures, workers losing their jobs, less flexibility in the organization, and negative attitudes toward technology change. The robotization disadvantages can offset some of the operational advantages derived from automation, and have an impact on the sustainability of business operations. At the same time, empirical studies that examine both the positive and negative aspects of automation's impact on sustainable business operations remain scarce. To get a more complete picture of these alternative mechanisms, therefore, a full grasp of their nature is required to offer a more equitable measurement of the organization change engendered by automation. Moreover, few studies have explored the mediating mechanisms between mechanical engineering and sustainable business operations, such as cost reduction and operational efficiency, quality improvement, and disadvantages of robotization. Research typically examines these constructs separately from one another without considering the interconnections between them in an integrated organizational structure. These research gaps are addressed by proposing and empirically testing an integrated framework to explore the mechanical engineering dimension and the impact on sustainable business operations by considering three key mechanisms: cost reduction and operational efficiency, quality improvement, and disadvantages of robotization. The study relates the positive and negative outcomes of automation in a single conceptual framework, allowing researchers to gain a broader perspective of the relationship between engineering capabilities and organizational sustainable performance. The proposed framework builds on the current knowledge by showcasing how sustainable business operation relies on the successful incorporation of engineering capabilities into automation strategies as well as the ability to adopt and implement technology. Therefore, the study makes a number of significant contributions to the literature and managerial practice. On one hand, it brings together mechanical engineering and robotic process automation as a single sustainability approach and it connects two research streams that have been progressing separately so far. Second, it further contributes to theory development by simultaneously considering the positive mediation role of cost reduction, operational efficiency and improvement in quality, as well as the negative mediation role of robotization disadvantages. Third, the results offer practical guidance for organizational decision-makers, as it is crucial to evaluate the technological efficiency of automation with the factors of workforce and operational flexibility during the planning and implementation of automation projects. The overall contribution of this research to the body of knowledge related to sustainable business operations is to show how engineering capabilities and intelligent automation are strategically integrated to create long-term organizational value.

2. Theoretical Foundation and Hypotheses Development

This study is grounded on the Resource-Based View (RBV) that suggests that organizations can attain sustainable competitive benefit from the effective use of valuable organizational resources and capabilities (Madhani, 2010). Mechanical engineering is considered a strategic skill (Navarro-Arcas et al., 2025) that helps businesses enhance manufacturing techniques, design processes for better efficiency, and implement robotic process automation (RPA). These capabilities add organizational value through increased operational efficiency, increased quality of products and processes, and support sustainable business (Fernando et al., 2019; Van Kleef & Roome, 2007). Based on this, the following three mechanisms are proposed in Figure 1, through which mechanical engineering has an indirect influence on sustainable business operations: cost reduction and operational efficiency, quality improvement, and robotization disadvantage. The depressing aspects of over-automation like job losses and unnecessary rigidity of processes are referred to as the disadvantage of robotisation, while cost reduction and quality improvement are seen as value-creating aspects that enhance sustainability. Therefore, the sustainable business operations rely on the capabilities of the organization to make effective use of engineering capabilities and challenge associated with automation.

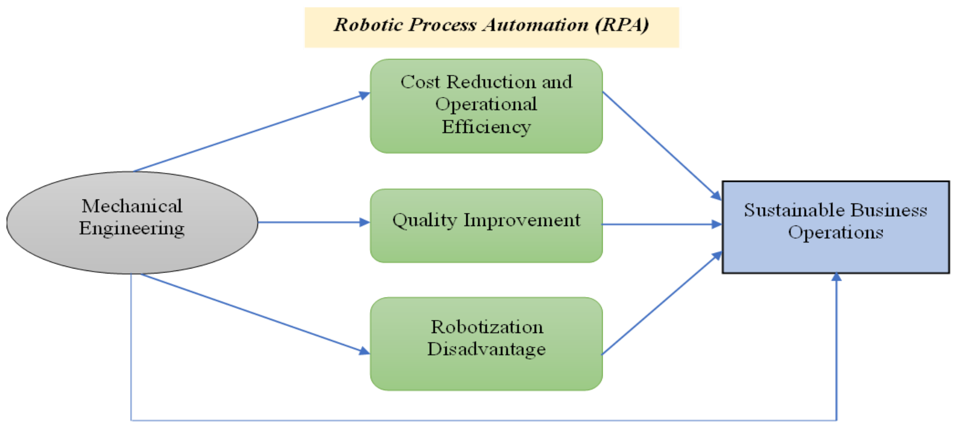

Figure 1: Framework of the Study Showing the Relationship Between Mechanical Engineering, RPA and Sustainable Business Operations

2.1 Mechanical Engineering and Sustainable Business Operations

Mechanical engineering is a key discipline in boosting the efficiency of production systems (Björkdahl, 2009), as it is used to design, optimize, and maintain efficient system. Modern mechanical engineering combines cutting-edge technologies, process optimization, and engineering innovation (Orlov et al., 2022), all aimed at minimizing resource waste, increasing the reliability of the equipment, and fostering environmentally friendly production methods. These engineering abilities allow organisations to make better use of materials, energy and human resources and ensure high productivity and consistent operations. Mechanical engineering is an asset for the organization and it is a valuable organizational capability that enhances the capability of firms to sustain long term performance (Lizunkov et al., 2016). Well-designed engineering systems also support ongoing process improvements, minimize disruptions at the plant and increase the ability to adapt to the evolving demands of the market. In the era of organizations aiming to sustain their operations while keeping a focus on their economic goals, engineering-driven innovations become vital to achieve effective and sustainable business operations (Manage, 2014). Hence, the companies with high mechanical engineering competencies are more likely to develop sustainable business operations through improving the utilization of resources, the effectiveness of operations, and the long-term competitiveness of the company. Given these arguments, the following hypothesis is suggested:

H1. Mechanical engineering has a positive influence on sustainable business operations.

2.2 Mechanical Engineering, Cost Reduction and Operational Efficiency, Quality Improvement and Robotization Disadvantage

Mechanical engineering plays a crucial role in cost reduction and improving operational efficiency within an organization (Texis et al., 2019) by optimizing production processes, enhancing equipment performance, and preventing process inefficiencies. Engineering innovations help companies optimize their workflows, minimize machine downtime, and maximize resource use, which can help lower operating costs and boost productivity. Advanced engineering methods also allow for the process to be standardized and preventive maintenance efforts to be improved, thereby minimizing waste and improving the reliability of the process. Engineering skills are strategic resources for an organization that enhance its operational performance and generate sustainable competitive advantages (Seraj & Sundram, 2026). Companies that have robust mechanical engineering skills will be better equipped to have efficient processes in place (Dudukalov et al., 2021), which will be able to minimize production costs and maximize output and operational efficiency. Thus, the following hypothesis is proposed:

H2. Mechanical engineering has a positive effect on cost reduction and operational efficiency.

Mechanical engineering is an indispensable profession that contributes to the improvement of product and process quality by designing products with accuracy, optimizing the processes, and continually innovating different technologies (Ambadekar et al., 2025). Engineering principles enhance the precision of the manufacturing process, the reliability of the equipment, and the consistency of the manufacturing process, thereby reducing the number of defects and increasing the quality of the manufacturing products. Advanced monitoring systems and standardized production processes in modern engineering practices also assist with quality assurance, ensuring consistency in operations (Ambadekar et al., 2025). Mechanical engineering as an important organizational resource for providing superior quality and ensuring competitive advantage (Riedel et al., 1991). Business organisations that make good use of mechanical engineering skills can make steady enhancements to their products and processes (Björkdahl, 2009), as well as ensure they are meeting expectations and industry standards. Thus, it is expected that better mechanical engineering skills will have a positive impact on the quality improvement of the organization. Therefore, it is hypothesized that:

H3. Mechanical engineering has a positive effect on quality improvement.

Mechanical engineering supports the use and incorporation of robotic systems into the activities of an organization by designing processes that enable process automation and advanced manufacturing technologies (Zheng et al., 2023). With the increasing adoption of robotics and automated systems in various organizations, engineering skills are driving the change towards technology-driven operations (Rajkumar et al., 2024). Increased automation can also create some organizational issues, however, such as job loss, shortness in process, lack of flexibility in workflow, and reliance on automated processes. Among these results, some can be grouped under the term "robots' disadvantages". Institutions with better mechanical engineering capabilities are more likely to use more automation and thus more likely to encounter greater challenges as a result of robotization. Thus, it is hypothesized that:

H4. Mechanical engineering has a positive effect on robotization disadvantage.

2.3 Cost Reduction and Operational Efficiency, Quality Improvement, Robotization Disadvantage and Sustainable Business Operations

Cost reduction and operational efficiency are crucial factors in the sustainable operation of a business (Akeem, 2017; Madanhire & Mbohwa, 2016), as they help companies to enhance productivity while reducing resource usage and operational waste. Streamlined business processes help to keep production costs low, allocate resources effectively, and make the best use of labour, equipment and energy (Ezeh et al., 2023). These enhancements boost an organization's competitiveness and promote long-term economic sustainability. Based on RBV, operational efficiency is the capacity of an organization to be able to generate extra value from its internal resources and retain competitive advantage. Additionally, reduced operating costs offer organizations financial flexibility, enabling them to invest in innovation and sustainable efforts. Therefore, companies with a higher degree of cost reductions and efficiencies will be better able to operate profitably, remain resilient and sustainable. Hence, it is hypothesized that:

H5. Cost reduction and operational efficiency have a positive effect on sustainable business operations.

Quality improvement is one of the most important factors that influence sustainable business operations (Bağış et al., 2026; Kuei & Lu, 2013) as it makes the processes more reliable, minimizes defects, and increases customer satisfaction. Continuous quality improvement in product and service delivery reduces rework, waste and disruption of operations (King & Patel, 2023), leading to better resource efficiency and sustainable performance. Good processes also enhance organizational reputation, customer loyalty and market competitiveness, all of which help to ensure business sustainability. Quality is a valuable organizational capability that gives the firm a competitive edge against rivals and enables its long-term competitive advantage (Tuan & Yoshi, 2010). The continuous quality improvement can help maintain operational excellence and help organizations adjust to changing market demands. Hence, organizations that focus on quality improvement are more likely to attain sustainable business operations by improving efficiency, customer value and organizational performance. Based on this, the following hypothesis is formulated:

H6. Quality improvement has a positive effect on sustainable business operations.

While the robotization has several advantages in operation (Khachaturyan et al., 2019; Nosova et al., 2024), the drawback can threaten the sustainability of business operation if it is not managed properly. When automation is overused, there is a potential risk of these contributing factors: workforce replacement, lack of flexibility in procedures, lack of flexibility in technology, and resistance to technology change (Damelang & Otto, 2024). They can have an adverse impact on staff morale, adaptability of the company and future operational resilience. Additionally, the expense of implementing and maintaining robotic systems can exceed the potential efficiencies gains if organizations do not have the ability to effectively manage automation. The literature suggests that resources become a source of competitive advantage only when they are utilised strategically and managed properly (Moderno et al., 2024). This can have negative consequences for unmanaged robotization, reducing the potential of the positive effects of automation on organizational performance and sustainability. Thus, it is hypothesized that:

H7. Robotization disadvantage has a negative effect on sustainable business operations.

2.4 Mediating role of Reduction and Operational Efficiency, Quality Improvement and Robotization Disadvantage between Mechanical Engineering and Sustainable Business Operations

By optimizing production processes, improving system design, and ensuring efficient integration of RPA, mechanical engineering plays a vital role in boosting organizational capabilities (Gavrilovskaya et al., 2021). These capabilities can provide value in a number of ways through operations, that ultimately affect sustainable business operations (McDougall et al., 2022). First, process optimization through engineering can help organisations cut their operational costs, boost productivity, and use resources more efficiently, thus making their operations more sustainable. Second, mechanical engineering brings precision, reliability and standardisation to products and processes (Bhad & Buktar, 2022), ensuring that customers are satisfied and that organisational performance is sustainable. On the other hand, higher levels of engineering-driven automation could also exacerbate the negative impacts of robotization, such as job loss, standardized processes, and a lack of organizational flexibility, all of which can threaten sustainability, unless properly managed. Consequently, the positive effects of mechanical engineering are expected to be transmitted to sustainable business operations via cost reduction and operational efficiency and quality improvement, and the negative ones via robotization disadvantage. These arguments lead to the following hypotheses:

H8. Cost reduction and operational efficiency mediate the relationship between mechanical engineering and sustainable business operations.

H9. Quality improvement mediates the relationship between mechanical engineering and sustainable business operations.

H10. Robotization disadvantage mediate the relationship between mechanical engineering and sustainable business operations.

3. Method and Material

The current study used a survey questionnaire to collect data from respondents. The questionnaire was developed by adapting scale items from previous studies. The scale of mechanical engineering was designed by Liu and Baker (2018) and consisted of seven items, which measure engineering competency with regard to engineering system design, engineering knowledge, problem-solving, experimentation and engineering communication. Cost reduction and operational efficiency was evaluated based on the following six items taken from Gomes and Seruca (2023), which measure the organization's capacity to reduce its operational costs, increase its productivity and efficiency of its processes by using RPA. Four of the items from Gomes and Seruca (2023) were used to measure quality improvement: process consistency, work accuracy, data reliability, and compliance with operational procedures. The robotization disadvantage was also assessed using four items adapted from Gomes and Seruca (2023), which aim to measure the potential negative effects of automation such as reduction in the workforce, lack of flexibility in procedures and increased complexity in operations. The sustainable business operations construct was assessed through a six-item scale created by Høgevold et al. (2015) measuring the level of commitment of the organizations to using their resources effectively, for the environment, economically and in their long term performance. The items of measurements were based on a five-point Likert scale.

3.1 Mechanical Engineering (Liu & Baker, 2018)

1. “An ability to apply knowledge of engineering help in business activities.
2. An ability to design and conduct experiments, as well as to analyze and interpret data promote business activities.
3. An ability to design a system, component, or process through engineering help in business activities.
4. An ability to function engineering process leads business operations.
5. An ability to identify, formulate, and solve engineering problems is helpful in business activities.
6. An understanding of professional and ethical use of engineering promote business.
7. An ability to communicate effectively through engineering applications promote business.”

3.2 Cost Reduction and Operational Efficiency (Gomes & Seruca, 2023)

1. “RPA enables the company to reduce efforts.
2. RPA enables the company to reduce the cost of transactions.
3. RPA enables to increase the work capacity of the areas.
4. RPA allows to reduce the time processing of tasks.
5. RPA allows to increase the productivity of the company.
6. RPA allows to increase employees’ productivity.”

3.3 Quality Improvement (Gomes & Seruca, 2023)

1. “RPA performs the work in a precise way reducing the number of errors.
2. RPA allows to increase work consistency and compliance with procedures.

3. RPA produces reliable data.
4. RPA increases the quality of processes.”

3.4 Robotization Disadvantage (Gomes & Seruca, 2023)

1. “RPA leads to layoffs.
2. RPA leads to hiring reduction.
3. RPA adds new unnecessary tasks.
4. RPA implies greater procedural rigidity.”

3.5 Sustainable Business Operations (Høgevold et al., 2015)

1. “Engineering techniques make the most efficient use of the resources available in the environment.
2. Engineering techniques focus on environmental issues.
3. Engineering techniques focus on survival in the marketplace.
4. Engineering techniques focus on economic considerations.
5. Engineering techniques saved money to the company at the beginning of implementation.
6. Engineering techniques are based on environmental monitoring.”

The target population included employees from automotive manufacturing industry which include: mechanical engineers, production engineers, operations, automation specialists, maintenance managers, quality managers, and plant supervisors. The automotive manufacturing industry was chosen because it has a broad range of applications for mechanical engineering and RPA throughout the manufacturing, assembly, quality inspection, logistics, and maintenance processes. Thus, the respondents from this industry have a lot of hands-on experience in the relationship between engineering and automation technologies, operational efficiency and sustainable business practices. For the respondents to respond to the issues with sufficient knowledge of organizational engineering and automation, employees with at least one year of professional experience were selected for the study.

In this study, Stratified Random Sampling method was used to get representative of respondents from various functional department of automotive manufacturing organizations. At first participating companies were asked to submit lists of their employees who worked in the engineering, production, quality management, maintenance, automation and operational departments. Different departments were treated separately due to the fact that they are functional roles directly related to mechanical engineering and RPA. The data was collected in the form of self-administered questionnaires in both hardcopy and electronic versions for a three-month period. Respondents were briefed on the academic purpose of the study, their responses being confidential and that their responses were voluntary prior to participation. Carefully completed questionnaires were reviewed and incomplete and inconsistent questionnaires were not used in statistical analysis. This data set proved to be adequate for analysis of the postulated relationships between the variables investigated. After screening the questionnaires for missing values, incomplete questionnaires, or response inconsistencies, 202 usable questionnaires were left for the final statistical analysis.

4. Data Analysis

Reliability and convergent validity were calculated for all the constructs in study and presented in Table 1. Cronbach's alpha values are between 0.806 and 0.947, and composite reliability values are between 0.874 and 0.957, which are greater than the recommended value of 0.70 (Shrestha, 2021; Tanveer & Latif, 2025). All of the measurement scales showed satisfactory internal consistency reliability. Likewise, the average variance extracted (AVE) ranged from 0.536 to 0.773, which show that more than half of the variance in the respective indicators is explained by each construct and thus demonstrate convergent validity. Moreover, all the loadings are greater than the recommended value of 0.60, indicating that the items observed were an adequate representation of their underlying constructs.

Table 1 (a): Measurement Model Results

Construct	Items	Alpha	Composite Reliability	AVE	Loading
Cost Reduction and Operational Efficiency	CROE1	0.924	0.94	0.725	0.841
	CROE2				0.874
	CROE3				0.885
	CROE4				0.895
	CROE5				0.813
	CROE6				0.796

Table 1 (b): Measurement Model Results

Construct	Items	Alpha	Composite Reliability	AVE	Loading
Mechanical Engineering	ME1	0.947	0.957	0.76	0.83
	ME2				0.86
	ME3				0.856
	ME4				0.899
	ME5				0.898
	ME6				0.89
	ME7				0.87
Quality Improvement	QI1	0.806	0.875	0.64	0.615
	QI2				0.849
	QI3				0.882
	QI4				0.827
Robotization Disadvantage	RD1	0.902	0.932	0.773	0.875
	RD2				0.879
	RD3				0.887
	RD4				0.877
Sustainable Business Operations	SBO1	0.827	0.874	0.536	0.748
	SBO2				0.782
	SBO3				0.761
	SBO4				0.746
	SBO5				0.674
	SBO6				0.677

There are three methods to examine discriminant validity which include AVE square root, HTMT and cross-loading (Hussain, 2023; Yusoff et al., 2020). In this study, the discriminant validity test was conducted based on the AVE square root and the results are presented in Table 2 and graphically represented in Figure 2. The square root of the AVE for each construct is larger than the inter construct correlations, which meets the recommended criterion of discriminant validity. Therefore, scale items are different from each other's for all constructs; mechanical engineering, cost reduction and operational efficiency, quality improvement, robotization disadvantage, and sustainable business operations.

Table 2: AVE Square Root

	CROE	ME	QI	RD	SBP
Cost Reduction and Operational Efficiency	0.852				
Mechanical Engineering	0.823	0.872			
Quality Improvement	0.587	0.59	0.8		
Robotization Disadvantage	0.415	0.431	0.769	0.879	
Sustainable Business Operations	0.702	0.688	0.707	0.706	0.732

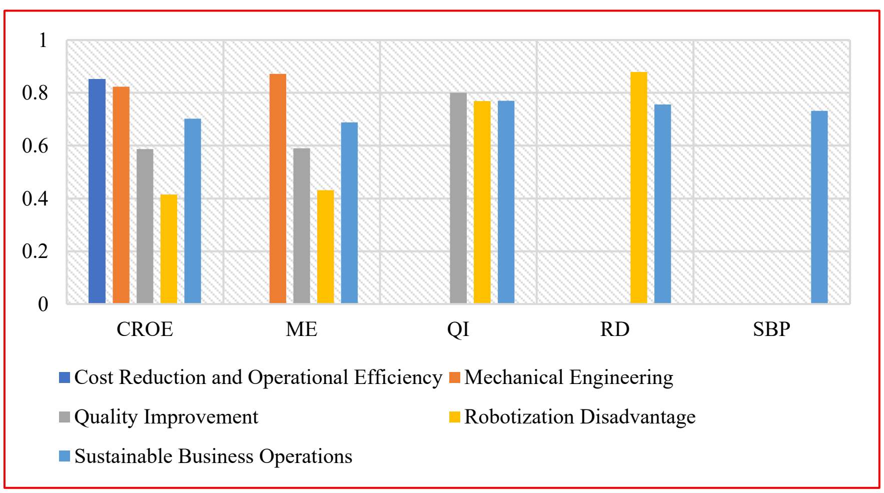

Figure 2: AVE Square Root

Table 3 shows the results of the structural model that is directly related to the constructs in the study as shown in Figure 3 (Structural Model). T-value 1.96 and beta value was used to test the study hypotheses (Aljumah et al., 2026). The results show that Sustainable Business Operations ($\beta = 0.162$, $t = 2.980$, $p = 0.003$) is significantly directly influenced by Mechanical Engineering, consequently H1 is accepted. Mechanical Engineering also positively influences Cost Reduction and Operational Efficiency ($\beta = 0.823$, $t = 50.824$, $p < 0.001$), Quality Improvement ($\beta = 0.590$, $t = 16.476$, $p < 0.001$), and Robotization Disadvantage ($\beta = 0.431$, $t = 8.367$, $p < 0.001$), supporting H2, H3, and H4. Additionally, Sustainable Business Operations is significantly influenced by Cost Reduction and Operational Efficiency ($\beta = 0.289$, $t = 4.975$, $p < 0.001$), and Quality Improvement ($\beta = 0.170$, $t = 3.057$, $p = 0.002$) and significantly negatively influenced by Robotization Disadvantage ($\beta = -0.436$, $t = -8.671$, $p < 0.001$), supporting H5, H6, and H7. All hypothesized direct relationships are supported by these results.

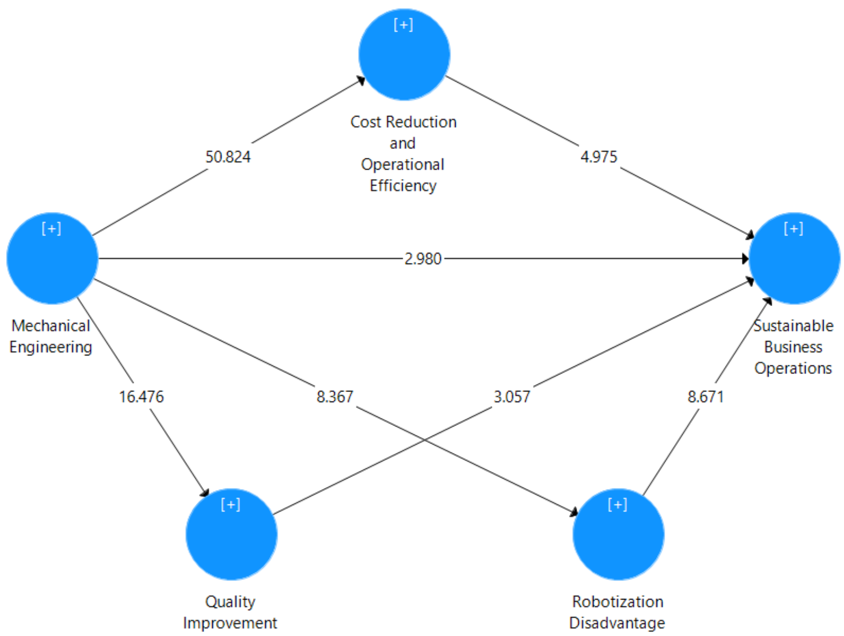

Figure 3: Structural Model

Table 3: Path Coefficient-Direct Effect Results

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
Cost Reduction and Operational Efficiency -> Sustainable Business Operations	0.289	0.289	0.058	4.975	0
Mechanical Engineering -> Cost Reduction and Operational Efficiency	0.823	0.824	0.016	50.824	0
Mechanical Engineering -> Quality Improvement	0.59	0.596	0.036	16.476	0
Mechanical Engineering -> Robotization Disadvantage	0.431	0.436	0.052	8.367	0
Mechanical Engineering -> Sustainable Business Operations	0.162	0.156	0.054	2.98	0.003
Quality Improvement -> Sustainable Business Operations	0.17	0.17	0.056	3.057	0.002
Robotization Disadvantage -> Sustainable Business Operations	-0.436	-0.439	0.05	8.671	0

The mediation analysis results are presented in Table 4 and the graphical presentation of the indirect effect estimates is presented in Figure 4. The findings show that there is a significant mediation of the relationship between Mechanical Engineering and Sustainable Business Operations by Cost Reduction and Operational Efficiency ($\beta = 0.238$; $t = 4.973$; $p < 0.001$), which supports H7. In the same way, Quality Improvement significantly mediates this relationship (β = 0.100, t = 2.919, p = 0.004), which supports H8. Moreover, the mediating effects of Robotization Disadvantage proved to be significant in the study, with a significant negative path from Mechanical Engineering to Sustainable Business Operations (β = −0.188, t = 6.213, p < 0.001), which supports H9. The results showed that Mechanical Engineering has a positive effect (cost reduction, operational efficiency, and quality improvement) and a negative effect (disadvantage of robotization) which confirms the proposed conceptual framework of mediation.

Table 4: Path Coefficient-Indirect Effect Results

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
Mechanical Engineering -> Quality Improvement -> Sustainable Business Operations	0.1	0.102	0.034	2.919	0.004
Mechanical Engineering -> Cost Reduction and Operational Efficiency -> Sustainable Business Operations	0.238	0.238	0.048	4.973	0
Mechanical Engineering -> Robotization Disadvantage -> Sustainable Business Operations	-0.188	0.191	0.03	6.213	0

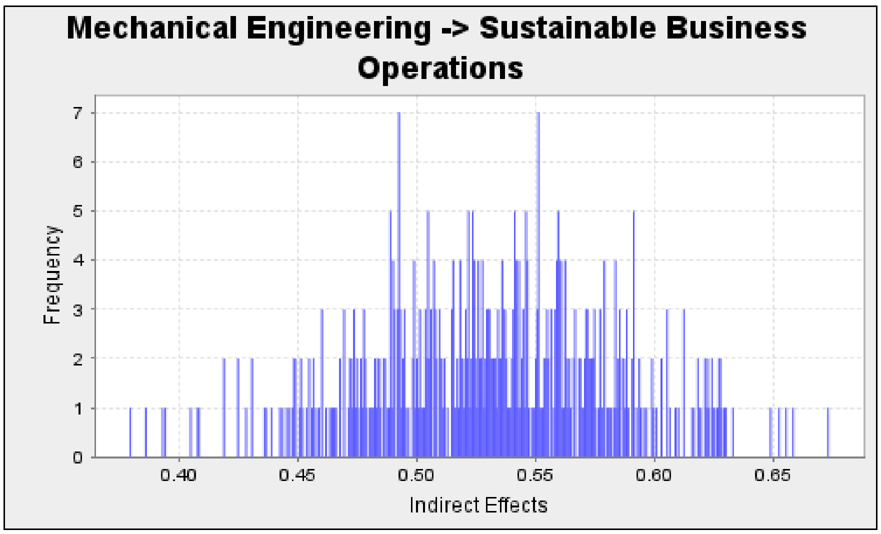

Figure 4: Indirect Effect Histogram

5. Discussion on Findings

The results offer a comprehensive overview of the role of mechanical engineering in the support of sustainable business operations, both directly and indirectly. As in the RBV, the findings show that engineering capacities are valuable internal resources that improve the operational performance and sustainable development of an organisation. Findings of H1 highlighted that mechanical engineering has a positive impact on sustainable business operations. Companies with more advanced mechanical engineering skills have the ability to maximize production systems, maximize use of resources and boost operational resilience (Olodu et al., 2026). Mechanical engineering helps companies incorporate new manufacturing technologies (Olodu et al., 2026), increase process reliability and minimize process inefficiencies, thereby establishing sustainable value for the organization. The results are supportive of the RBV which states that distinctive organizational capabilities directly lead to sustained competitive advantage (Kero & Bogale, 2023; Nayak et al., 2023; Raduan et al., 2009). The findings also build upon past engineering literature by providing evidence of mechanical engineering's role beyond only technical performance toward organization-level objectives for sustainability.

The H2 and H3 involved the impact of mechanical engineering on cost reduction and operational efficiency, and quality improvement. Both hypotheses were confirmed, indicating that engineering capabilities make a significant contribution to organizational performance through its ability to optimize the production processes and to increase the quality of the operations. Creative engineering solutions lessen production expenses by allocating resources effectively (Wao, 2018), implementing preventative maintenance and optimizing workflow and equipment downtime. At the same time, engineering enhances the accuracy of the processes (Ramesh et al., 2025), uniformity of the products, and reliability of the processes during operation, thereby delivering superior product quality. These results further corroborate earlier automation and manufacturing research which concluded that engineering knowledge is a critical factor in operational excellence. Most of all, the findings show that companies can balance efficiency and quality to achieve sustainable performance.

The H4 was confirmed that mechanical engineering has a positive impact on the robotization disadvantage. While automation improves organizational performance (Sudhakar et al., 2025; Wong & Ngin, 1997), more engineering capability has the potential to drive faster adoption of robotic systems, thereby driving up the risk of issues like workforce displacement, procedural inflexibility, and organizational reluctance to technological change. This outcome helps to balance the interpretation of automation, recognising opportunities and implementation challenges. Therefore, in addition to investing in engineering, organizations must invest in employee development, organizational change management, and flexible operational strategies to help reduce risks associated with automation.

The H5, H6 and H7 hypotheses examined the impact of cost reduction and operational efficiency, quality improvement and robotization disadvantage on the sustainable operation of the business. The results confirm that cost reduction and operational efficiency can strongly contribute to improving sustainability, by using resources more effectively, reducing operational costs and boosting productivity. Similarly, quality improvement also has a positive effect on sustainable business practices (Akanmu et al., 2020; Aryanasl et al., 2016; Fok et al., 2022) by reducing defects, waste and enhancing customer satisfaction. By contrast, robotization disadvantage has a negative impact on sustainability, suggesting that uncontrolled disadvantages to robotization can have negative effects on organizational flexibility and long-term performance. In combination, these findings show that in order to operate their business in a sustainable way, organizations need to minimise the operational costs while at the same time managing the unintended consequences of automation proactively.

Finally, the mediation analysis gives further theoretical insights as it showed that the disadvantages of the mechanical engineering, sustainable business operations relationship was significantly mediated by cost reduction and operational efficiency, quality improvement, and robotization. The results demonstrate that engineering capacities have an impact on sustainability not only directly within engineering but also through many operational paths. Operational efficiency and quality are positive pathways of transmission and robotization disadvantage is a negative pathway of transmission that partially balances the advantages of engineering driven robotization. The integrated view is able to build on the previous work by taking into account both the enabling and constraining effects of automation in a single framework. The results of the analysis highlight that sustainable business operations can be achieved by strategically embedding mechanical engineering capabilities in RPA.

6. Conclusion

In this research, the relationship between mechanical engineering and sustainable business operations was studied and the role of cost reduction and operational efficiency, quality improvement, and robotization disadvantage was investigated as mediating variables. The empirical results confirm that mechanical engineering is a strategic organizational capability that directly contributes to sustainable business operations and that has an indirect impact on sustainable business through various mechanisms. Operating efficiency and cost reduction, combined with quality improvement, boost sustainable business performance by improving productivity, using resources more efficiently and making business operations more reliable. On the other hand, the disadvantage of robotisation has a negative impact on sustainability, which means that over-automation can lead to problems in the organisation.

The mediation results also demonstrate the positive and negative ways in which engineering capabilities can be the source of organizational values. The findings suggest a perspective on the relationship between mechanical engineering and robotic process automation, acknowledging that automation brings substantial advantages in terms of the benefits it provides for operations but also presents managerial challenges. On an overall perspective, the study furthers the RBV by providing an example of engineering capabilities that are related to sustainable business operations through complemental operations processes. The findings also offer guidance for its application that organizations can use to implement automation technologies in ways that are most likely to lead to their sustainability and operational efficiency, while maintaining high quality.

7. Implications of the Study

The study has theoretical and practical implications. It is an extension of the RBV that incorporates mechanical engineering and robotic process automation into a unified framework to understand sustainable business operations. The results show that engineering skills add value by means of operational efficiency, quality enhancement and outcomes related to automation, enriching the engineering management and organizational sustainability literature. In practice, managers need to develop engineering skills as well as automation technology to boost productivity, minimize operating costs and quality of the process. To mitigate the downside of robotization, workforce reskilling, change management initiatives, and flexible operational policies should also be considered as part of an organization's strategy. To achieve sustainable operational performance and long-term organization competitiveness, decision-makers should use a balanced approach to automation, which is a mix of technology and human resources development.

8. Limitations and Directions for Future Research

There are a few limitations of this study that could be addressed in future studies. First, this study considered mechanical engineering as whole construct, future studies should consider in various dimensions of mechanical engineering. Second, this study only examined the automotive manufacturing sector, therefore the results may not be generalizable. The proposed framework needs to be tested in other manufacturing and service sectors for further validation. Third, future research could include other organisation factors, like digital transformation capability, organisational culture, leadership support for digital transformation, and employee readiness for digital transformation, to gain a broader knowledge about sustainable business operations in the context of increased automation.

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