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ANALYSIS OF PRODUCT DEVELOPMENT TECHNIQUES AND SUSTAINABLE DESIGN IN ELECTRICAL MANUFACTURING: A CASE STUDY OF GENERAL COMPANY FOR ELECTRICAL INDUSTRIES, DIYALA

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ABSTRACT: This research is centred on evaluating the operational performance of a company by assessing the utilisation of various product development techniques. Specifically, it investigates the degree of implementation and the corresponding gaps in approaches such as green manufacturing, total quality management, value engineering, and computerised production systems. In addition to this analysis, the study undertakes a quantitative examination of the influence exerted by corporate sustainability strategy and policy, sustainable product requirements, and the integration of sustainability within product development processes on sustainable product design and development. A combined methodological approach was adopted, incorporating both a case study and causal analysis. The selected case study site was the General Company for Electrical Industries, involving a sample of 57 managerial personnel. These participants responded to a checklist designed to align with the research objectives and scope. The findings reveal notable deficiencies in the implementation of the examined product development techniques. Based on these insights, the study proposes that company leadership should pursue a more balanced emphasis across all techniques, advocating for increased application rates to enhance overall effectiveness and competitive performance in the relevant industrial sector. In the second phase of the investigation, data were gathered from an additional sample of 213 respondents. This dataset was analysed using both measurement and structural model methodologies. The results affirm the measurement model's reliability, as well as its convergent and discriminant validity. Furthermore, structural equation modelling revealed that the integration of sustainability into product development and the specification of sustainable product requirements both exert a statistically significant and positive impact on sustainable product design and development. The study concludes with policy recommendations that underscore the importance and strategic relevance of sustainable product development and design, informed by empirical evidence.

Keywords: Product Development Techniques, Green Manufacturing Technique, Total Quality Technique, Value Engineering Technique, Computerized Production Technique.

1. Introduction

Product development plays a critical role in generating returns that contribute to a company's survival, expansion, and sustained presence in a competitive business environment. It encompasses all activities related to assessing existing products, pursuing their enhancement, or evaluating the potential for their replacement with alternatives that better satisfy customer demands. This function necessitates the collaborative involvement of various departments, including finance, which secures the requisite funding, engineering design, which converts customer needs into viable models, and marketing, which is responsible for identifying and understanding those needs. The responsibility for executing effective product development initiatives primarily lies with operations management, as the processes involved in modifying current offerings or introducing new ones are governed by the financial feasibility of the production system, as well as by the nature and application of contemporary technologies utilised in both product and process design.

The present study was conducted at the General Company for Electrical Industries, located in Diyala. This company manufactures a range of electrical equipment tailored to the needs of its target market and is recognised as one of the key enterprises under the jurisdiction of the Iraqi Ministry of Industry and Minerals. Established in 1974, the company comprises multiple production units, including those for electrical scales, steam and standard irons, spark plugs, and ceiling fans. Its product portfolio expanded in 1983 with the addition of an electrical transformer project, followed by the launch of an argon gas production facility in 1990. In 2003, a longitudinal cable production plant was added. The company continues to operate across these product lines, serving both institutional and individual clients in the electrical sector, while consistently seeking avenues for innovation to address domestic market demands and enhance technological competence within its field.

Given that the environmental footprint of a product is largely determined during its initial development phases (Borgianni, Cascini, & Rotini, 2018), transitioning to a sustainable economic model necessitates the design of products that minimise such impacts while delivering improved sustainability performance. Over time, products demonstrating superior sustainability metrics have gained a competitive advantage in the marketplace (Parmentola & Tutore, 2023). Moreover, increasing consumer demand for environmentally responsible products and heightened regulatory pressures have compelled businesses to operate more ethically (Lövdahl, Hallstedt, & Schulte, 2023). In response to these challenges, manufacturing firms have intensified efforts to reduce the environmental, social, and economic implications of their products throughout the entire product life cycle. The concept of sustainable product development (SPD) specifically involves the incorporation of sustainability principles throughout the development process (Vilochani, McAloone, & Pigosso, 2024a).

To examine the integration of sustainability within product development, a total of 61 SPD management practices were identified through a comprehensive synthesis of existing literature. These practices represent established procedures for embedding sustainability into product development and associated operations. Subsequently, these practices were categorised under 11 principal thematic areas. Despite the extensive compilation of SPD practices, the extent to which they are applied within manufacturing enterprises remains uncertain (Vanegas et al., 2018). Although considerable research exists regarding the sustainability perspective of product development, there remains a lack of detailed quantitative analysis on the influence of variables such as corporate sustainability strategy and policy, sustainable product requirements, and sustainability integration within product development. Addressing this research gap, the current study offers a substantial contribution to the literature on sustainable product development and design.

2. Literature Review

Heightened global competition, accelerating technological advancements, and evolving market dynamics have compelled organisations to invest in the development of new products, not solely for profit generation but also as a necessity for continued existence. This strategic orientation has become fundamental to long-term success. A wide array of sophisticated product development techniques are employed to reassess and enhance existing products and to pilot the introduction of innovative offerings. These methods are continuously evolving and remain incomplete, serving dual objectives. The first is to transform such efforts into tangible organisational outcomes that generate financial returns. When correctly conceptualised and implemented, new products can significantly stimulate organisational growth in ways that existing offerings often cannot achieve (Owens & Davies, 2000). Among the most critical strategic decisions within operations management, which contribute to organisational sustainability and endurance, is the process of product positioning. Product development itself has emerged as a vital concept encompassing a range of corporate activities. The necessity for engaging in product development arises from various interconnected factors, such as intensified market rivalry, limited product life cycles, continuous scientific and technological breakthroughs, and the evolving nature of knowledge and innovation.

2.1. New Product Introduction Strategies

The introduction of a new product refers to the transformation of a market opportunity into a tangible offering available for consumer purchase. This offering may take the form of either a product or a service and is influenced by several critical factors, including customer preferences, market share, required capital investment, and competitive landscape. Consequently, conducting a feasibility study represents the foundational stage of any product development strategy. The overarching goal is to either enhance existing offerings or design new ones that not only satisfy but also surpass consumer expectations. Enhancing established products forms a central component of the strategic approach adopted by successful organisations, as product development serves as a catalyst for innovation and differentiation within an increasingly dynamic and competitive business environment. This process encompasses a series of stages, including analysis, planning, design, and testing, and necessitates the application of appropriate methodologies and tools to maximise the potential for commercial success (Dąbrowski, 2023). A variety of strategic models exist to guide the introduction of new products. The first is the market-driven strategy, which focuses on aligning product development with market demands. Under this approach, organisations aim to produce offerings that meet current consumer needs, adhering to the principle of producing what can be sold. This strategy is inherently interactive, involving close collaboration among functions such as marketing, operations, and process engineering.

The second model is the technology-driven strategy, wherein product development is influenced primarily by the capabilities of existing production technologies. In this case, the strategic focus shifts towards selling what the organisation is capable of producing, necessitating a synchronised effort between advanced technological resources and marketing functions. A third approach, known as the inter-functional strategy, emphasises that successful product development requires comprehensive collaboration among various organisational departments, including marketing, operations, and finance. This strategy is not governed exclusively by technological considerations or by market demands but instead reflects a coordinated, organisation-wide effort across all functional areas.

2.2. Product Development Strategies

Organisations implement various product development strategies, all of which aim to introduce new offerings that satisfy customer needs while delivering added value (Souza, Bayus, & Wagner, 2004). The most significant of these strategies include:

1. **Product Diversity:** This strategy involves establishing adaptable production systems that support a broad range of product offerings tailored to meet diverse customer preferences. It focuses on maintaining efficiency in terms of cost, quality, and speed, while also avoiding vulnerabilities to intense market competition through designs that are flexible and capable of appealing to customers.

2. **Competing by Design:** Under this approach, product development is guided by elements such as visual appeal, functional simplicity, safety features, and ease of maintenance. The aim is to enhance product attractiveness in order to gain a leadership position in the market.

3. **Creative Offers:** This strategy relies on strong research and development capabilities, enabling the organisation to swiftly introduce innovative products. The ability to consistently bring new ideas to market is central to maintaining a competitive edge.

4. **Service:** Within this strategy, the organisation integrates value-added services alongside its core products. These services are designed to complement the main offering, enhancing overall customer satisfaction and creating a more complete product experience.

2.3. Product Development Techniques

This strategy reflects the growing ethical and environmental responsibilities placed upon organisations (Öhman, 2008), particularly in light of the emergence and diffusion of the green manufacturing paradigm. This approach emphasises environmental responsiveness throughout the stages of product design, production, and end-of-life disposal, by promoting practices such as reuse, renewal, and safe disposal of product components across the full product life cycle. Consequently, it becomes essential for operations managers, engineers, and value analysis teams to examine the complete life cycle of products—from the initial design phase through to final production—in order to mitigate adverse environmental impacts, preserve ecological integrity, and ensure the sustainable use of natural resources. Green manufacturing, therefore, encompasses a structured set of integrated and synchronised processes designed to minimise, and ultimately eliminate, pollution by identifying its sources and applying innovative green strategies (Deif, 2011). This includes developing forward-thinking designs that enhance the environmental compatibility of industrial systems by promoting efficient resource utilisation and safeguarding renewable energy sources. In this context, ethical design principles are directed towards achieving the following objectives:

2.4. Total Quality Technique (TQT)

The primary objective of Quality Function Deployment (QFD) is to identify customer expectations for a product and to translate these expectations into corresponding design features that characterise the intended product (Akao, 2024). Understanding what truly satisfies the customer is central to this process, and achieving that understanding forms the foundation for delivering products aligned with customer needs. In Japan, during the late 1960s, researchers Dr. Mizuno Shigeru and Dr. Akao Yoji promoted QFD as a structured approach that begins with gathering input from customer demands and culminates in defining the technical specifications necessary to meet those demands (Mazur, 1993). QFD involves the systematic development and transformation of customer expectations by actively capturing the "voice of the customer." This voice is a fundamental component of QFD and serves to guide the translation of customer needs into specific quality attributes embedded within the design and production processes (Shen, Xie, & Tan, 2001). Central to this approach is the construction of one or more "Houses of Quality", which are matrices used to facilitate the transformation of information across stages. The initial matrix holds primary importance, serving as the foundation for the subsequent matrices. In this framework, the initial matrix translates the customer's preferred requirements into specific product or service characteristics. These characteristics are then transferred into the second matrix, which defines the essential processing operations. In the third matrix, these operations are further translated into key production tasks, and finally, the fourth matrix outlines the implementation requirements. Through this progression, the customer's perspective is systematically embedded into the technical and operational aspects of the product, ensuring that the final outcome is fully aligned with their expectations (Jones, 2003).

2.5. Value Engineering Technique

Value engineering represents a contemporary discipline particularly relevant for developing nations experiencing economic constraints (Emami & Emami, 2020). It is increasingly applied to serve critical objectives, including the equitable allocation of essential resources. As such, it functions as a cost-reduction strategy and is widely utilised by organisations operating in competitive markets to establish and maintain a strategic advantage. The principal focus of value engineering lies in lowering the overall cost of products or services without compromising their quality, thereby supporting organisational sustainability, growth, and continuity (Aseel Ali & Mohammed, 2022). This technique involves a set of structured activities that contribute to both the design and production of products, ensuring their reliability and functional performance. It offers an effective approach to managing operations by directly reducing costs and enhancing value through concentration on the core performance attributes required to satisfy customer expectations. Additionally, it includes a comparative evaluation of competitors to support continuous improvement in value engineering practices. To support these objectives, companies are encouraged to pursue robust design strategies aimed at minimising inherent variability in product features during manufacturing. This approach enhances product reliability by making its performance less susceptible to process fluctuations. Moreover, adopting a modular design is recommended, allowing products to be composed of distinct components that are easily replaceable or interchangeable. Such modularity simplifies maintenance and facilitates customisation, with products designed in this manner referred to as modular systems.

2.6. Computerized Production Technique

The concepts of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) are relatively recent innovations closely associated with the evolution of computing technology (Bi & Wang, 2020). Their practical adoption across industrial, academic, and governmental contexts spans roughly the past three decades. Structured academic instruction in CAD and Finite Element Analysis (FEA) emerged during the 1970s (Noor & Malone, 1997). CAD involves the interactive utilisation of computer systems for product design and the generation of engineering documentation. This technology significantly reduces both the time and cost associated with product development. It enables designers to manage even complex or intricate designs with increased efficiency and speed. Complementarily, CAM refers to the application of information technology, particularly specialised software tools, to oversee, regulate, and control production machinery and processes.

3. Research Methodology

The objective of this research is to examine the extent to which product development technologies are implemented within the General Company for Electrical Industries – Al-Waziriyah. It further aims to establish a hierarchy of these technologies by assessing their relative significance based on measured levels of application. This process is visually represented in Figure (1).

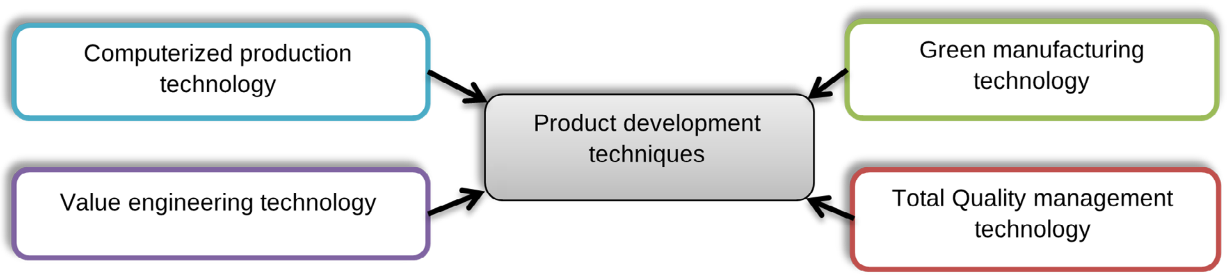

Figure 1: Product Development Techniques.

The researcher developed two hypotheses for empirical examination:

Hypothesis 1: Product development techniques fall into four categories applied by companies: (green manufacturing, total quality, value engineering, and computerized production).
Hypothesis 2: All product development techniques receive equal support from the General Company for Electrical Industries - Al-Waziriyah.

The researcher employed a case study methodology, focusing on a single business entity with the aim of enhancing its operational performance and extrapolating the findings to comparable organisations within the same industrial domain. The case study approach utilised a checklist as a primary instrument to assess the actual implementation of the research variables. This checklist was specifically developed by the researcher to align with the variables under investigation and was subsequently reviewed by subject matter experts in production and operations management to validate its accuracy and relevance to the practical context of the General Company for Electrical Industries – Al-Waziriyah.

The selection of the General Company for Electrical Industries – Al-Waziriyah as the research setting was based on its strategic significance within the local industrial landscape and its considerable impact on the business environment. The company's products hold a notable and influential position in the market. A purposive sampling technique was adopted to select participants from within the organisation. The sample comprised managerial personnel, including the general manager and their deputies, departmental and branch heads along with their respective assistants, all of whom participated in interviews and contributed to the collection of data via the research checklist. The total number of respondents in this qualitative phase amounted to 50 managers. In the second phase of the study, a quantitative approach was employed to examine the impact of corporate sustainability strategy and policy, sustainable product requirements, and the integration of sustainability into product development on sustainable product design and development. The questionnaire used for this purpose was developed based on previous scholarly work (Vilochani et al., 2024a; Vilochani, McAloone, & Pigosso, 2024b). The items were assessed using a five-point scale: Not Applied, Ad-hoc, Formalised, Measured, and Improved, to evaluate the degree of implementation across the specified dimensions. Data were gathered from a final sample of 213 participants and analysed using Smart PLS software to evaluate both the measurement model and the structural model.

4. Results and Discussion

4.1. Phase 1

The checklist was developed based on established facts and relevant administrative theories drawn from existing literature on the subject. It was subsequently reviewed by a panel of expert arbitrators specialising in the field. During the data collection process, interviews were conducted with managerial personnel at the General Company for Electrical Industries in Al-Waziriyah. These participants included the general manager, their deputies, heads of departments along with their assistants, and division managers and their assistants. In total, 57 managers participated, representing the sample covered in this phase of the research. Upon completion and collection of the checklists, the results were compiled and are presented in Table (1). Moreover, the findings displayed in Table (1) indicate that the research hypothesis lacks stability and that the company does not apply product development techniques in a consistent or balanced way.

Table 1: Checklists of Product Development Techniques in General Company for Electrical Industries (N=57).

	Product Development Techniques	
	Green Manufacturing Technique	Checkout
1	The company adopts the principle of preserving natural resources.	√
2	The company has a clear policy on the optimal use of natural resources.	×
3	The company is concerned with ethical issues agreed upon in society and the market.	×
4	The company allows its employees to submit positive suggestions related to the optimal use of resources.	√
5	The company contracts with research agencies specialized in environmental protection.	√
6	The company uses incidental production in manufacturing processes again.	√
7	The company emphasizes reducing the percentage of defective production that causes harm to the natural environment.	√
8	The company has a natural resources protection unit within its organizational structure.	√
9	The company returns its products from the consumer to the factory for renewal and maintenance purposes.	√
10	The company takes into account the aspects of protecting nature and humans in the early stages of product design.	√

	Percentage of Actual Application for Green Manufacturing Technique	**80%**
	Total Quality Technique	**Checkout**
11	The company cares about the desires of current and potential customers.	√
12	The company has a database of industrial and consumer customers.	√
13	The company meets the requests of its regular customers regarding changing some of the physical properties of the product.	√
14	The company adopts the principle that quality is the responsibility of everyone within the company.	×
15	The company gives production managers in its factories the authority to stop the production line in the event of a deviation from the required specifications.	×
16	The company subjects all manufacturing processes and treatments to review.	√
17	The company can modify the production path when defects are discovered in the treatments and manufacturing process.	√
18	The company views suppliers as strategic partners of the company.	×
19	The company maintains relationships with reputable and well-known suppliers in the industry in which it operates.	√
20	The company continuously evaluates its products from the time of receiving materials from suppliers until the goods are delivered to customers.	√
	Percentage of Actual Application for Total Quality Technique	**70%**
	Value Engineering Technique	**Checkout**
21	The company emphasizes identifying the aspects related to the value that the customer is looking for.	√
22	The company builds the added value of its products in the initial design stage.	√
23	The company is able to provide skilled operators in its production processes.	×
24	The company has unique resources that allow adding value to its products.	×
25	The company evaluates competitors' products to know the value they add to customers.	√
26	The company uses the balanced scorecard to identify critical aspects in adding value	√
27	The company emphasizes the durability of its products because it plays a major role in keeping the product in use for the longest possible period.	√
28	The company owns factories that produce its primary resources used in manufacturing.	×
29	The company is keen to have product designs that allow its parts to be replaced with other types when necessary.	×
30	The company balances between adding value and reducing production costs.	×
	Percentage of Actual Application for Value Engineering Technique	**50%**
	Computerized Production Technique	**Checkout**
31	The company directs all its managers to possess computer skills.	×
32	The company has an electronic data exchange system with suppliers.	×
33	The company uses cameras installed within production processes for monitoring purposes.	√
34	The company designs its products using the latest scientific applications in the field of computers.	×
35	The company subjects all operators and production managers to training courses in the field of using computers during manufacturing.	√
36	The company is trying to obtain the advantage of zero errors by relying on robots and computers in manufacturing.	√
37	The company believes in the idea of computerization and seeks to apply it in all areas of work within production.	√
38	The company can change the specifications of its products during manufacturing by reprogramming the computers and controlling production.	√
39	The company uses computers for the purpose of controlling production costs and identifying areas of excessive and unnecessary spending.	√
40	The company relies on the computer to control inventory levels within the production process.	×
	Percentage of Actual Application for Computerized Production Technique	**60%**

4.2. Discussion

The research findings reveal that the General Company for Electrical Industries applies product development techniques at differing levels. These results allow for the identification of specific application rates, which in turn make it possible to determine the extent of application gaps experienced by the company. This analysis is illustrated through the Pareto chart presented in Figure (2). Moreover, Figure (2) indicates that the General Company for Electrical Industries has not addressed the imbalance in its focus on product development techniques. Each of the four techniques has been implemented to differing extents and holds varying degrees of relative importance, as detailed in Table (2).

Table 2: Relative Importance and Sequences for Product Development Techniques in General Company for Electrical Industries.

Product Development Techniques	Actual Applications	Gaps	Relative Importance	Sequences
Green Manufacturing Technique	80%	20%	31%	1
Total Quality Technique	70%	30%	27%	2
Value Engineering Technique	50%	50%	19%	4
Computerized Production Technique	60%	40%	23%	3

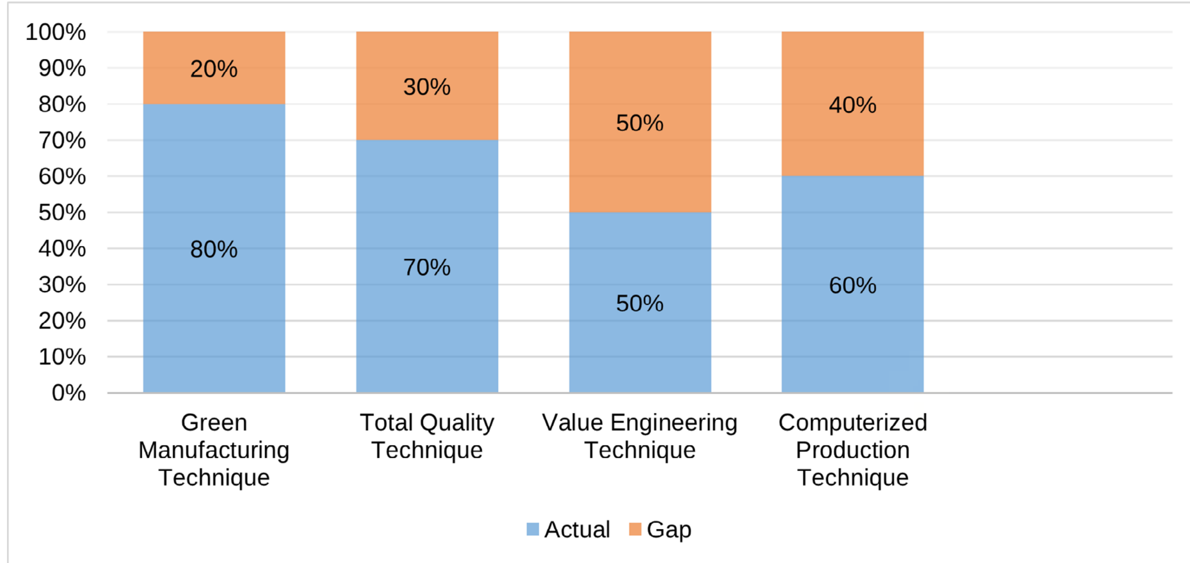

Figure 2: Actual Application and Gaps for Product Development Techniques from a Managers' View in General Company for Electrical Industries.

Difference in relative importance of each of product development techniques in company under study is a clear case that requires review by company's senior management. Order of importance for each requirement can be illustrated as a Pie Chart that calculates and plots the results as in Figure (3).

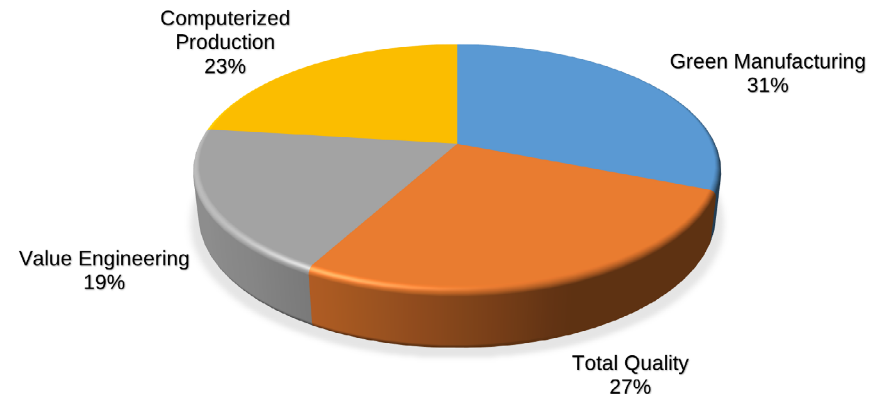

Figure 3: Relative Importance for Product Development Techniques in General Company for Electrical Industries.

It is evident that the company exhibits considerable deficiencies in the implementation of product development techniques, as detailed below:

1. **Green Manufacturing Techniques:** The company demonstrates a 20% implementation gap, reflecting an 80% application rate. This shortfall is attributed to limited emphasis on sustainability principles, with decision-making processes driven more by profit motives than by environmental responsibility. Additionally, regulatory compliance appears to take precedence over ethical considerations.

2. **Total Quality Techniques:** A 30% gap is identified in this area, corresponding to a 70% rate of application. Contributing factors include the failure to update product specifications, disregard for customer feedback, and the absence of an embedded quality-oriented organisational culture. The focus remains predominantly on production efficiency and profitability, rather than on fulfilling customer expectations.

3. **Computerised Production Techniques:** The company records a 40% implementation gap, with a 60% application rate. This deficiency is linked to inadequate digital competencies among staff, continued dependence on manual planning processes, and traditional procurement practices. Furthermore, the use of computer systems in inventory control is limited,

and computer-aided product design is entirely absent.

4. **Value Engineering Techniques:** The largest gap, at 50%, reflects a corresponding 50% application rate. This is largely due to dependence on underqualified personnel, restricted financial and technical resources, and reliance on obsolete production systems that lack the flexibility to respond to dynamic environmental conditions.

4.3. Phase Two

4.3.1. Analysis of Measurement Model

For the quantitative analysis, the study first applies the measurement model evaluation, developed using Smart PLS version 4. The structural representation is provided in Figure 4, where the observable items are displayed on the outer layer of the model, while the latent constructs are shown within the model using circular nodes. To assess Corporate Sustainability Strategy and Policy (CSSP), five measurement items were incorporated. Similarly, seven items were used to evaluate SPR, while eight items were utilised each for SIPD and SPDD. All measurement items across these constructs were assessed using a standard Likert scale to ensure consistency and reliability.

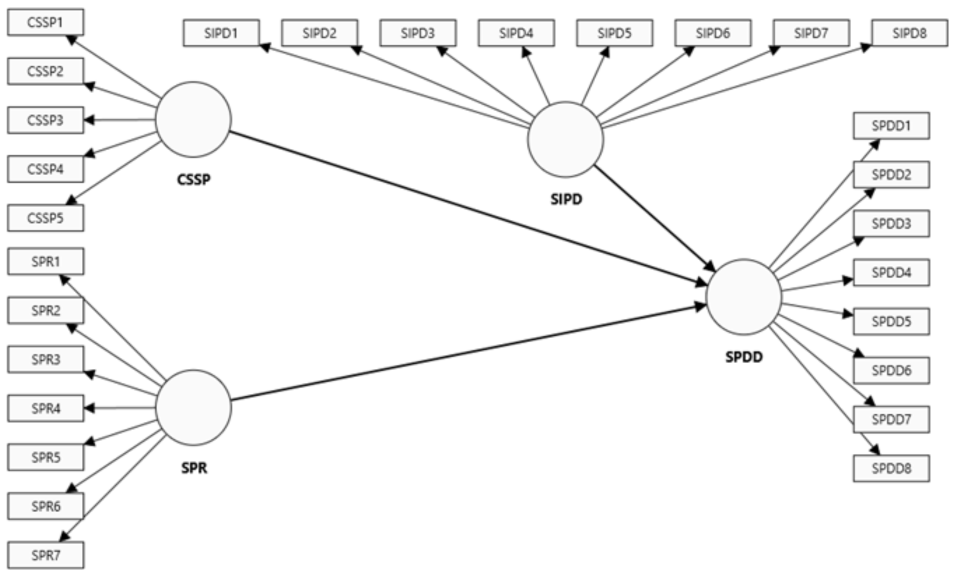

Figure 4: Measurement Model Input Diagram.
Note: CSSP: Corporate Sustainability Strategy and Policy, SPR: Sustainable Product Requirements, SIPD: Sustainability Integration into Product Development, SPDD: Sustainable Product Design and Development

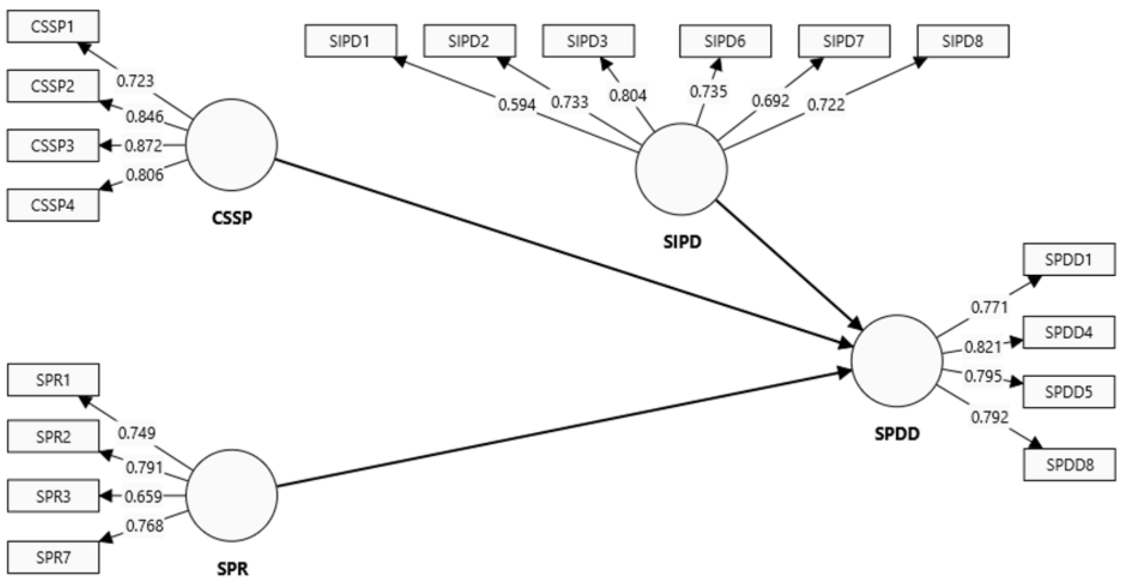

Figure 5: Measurement Model Output Diagram (Only the Items with Valid Loadings of Above 0.50).

Following the application of the PLS-SEM algorithm, the initial analysis revealed that several items within the measurement model exhibited low or negative factor loadings. As a result, these underperforming items were excluded from the model, and the algorithm was re-applied to reassess the structural integrity. In the refined model, indicators such as CSSP1, CSSP2, and so forth were used to measure the latent construct CSSP, displaying strong factor loadings ranging from 0.723 to 0.846. Similarly, for SPR, the corresponding indicator loadings ranged between 0.659 and 0.791. Regarding SIPD, which was measured using indicators SIPD1 through SIPD8, the factor loadings varied from 0.594 to 0.804, indicating generally acceptable levels of association. For SPDD, the indicator values were found to range between 0.771 and 0.792, suggesting a robust correlation between the latent variable and its associated observed items. In conclusion, the refined model, as illustrated in Figure 5, presents a well-structured alignment between latent constructs and their respective indicators.

The assessment outcomes for the model's reliability and convergent validity are presented in Table 3. As indicated, Cronbach's alpha values exceed the recommended threshold of 0.70, ranging between 0.742 and 0.830, thereby confirming acceptable internal consistency. Similarly, the composite reliability metrics, identified as rho_A and rho_C, also surpass the 0.70 benchmark, with observed values falling within the range of 0.777 to 0.854 for rho_A and 0.831 to 0.886 for rho_C. Additionally, Table 3 includes the Average Variance Extracted (AVE), which demonstrates that each construct explains more than 50% of the variance in its indicators, thereby meeting the minimum threshold. Collectively, the results reported in Table 3 validate both the reliability and convergent validity of the measurement model.

Table 3: Reliability and Validity Checks.

	Cronbach's Alpha	Composite Reliability (rho_a)	Composite Reliability (rho_c)	Average Variance Extracted (AVE)
CSSP	0.830	0.854	0.886	0.662
SIPD	0.809	0.826	0.862	0.512
SPDD	0.807	0.811	0.873	0.632
SPR	0.742	0.777	0.831	0.553

Discriminant validity was assessed using the Heterotrait-Monotrait (HTMT) ratio, with the results displayed in Table 4 for all latent variables under investigation. A threshold value of 0.90 is generally recognised as the upper limit for establishing discriminant validity between constructs. Based on the reported results, none of the HTMT values exceed this threshold, with the highest observed value being 0.76. These findings indicate that satisfactory discriminant validity is present across all constructs in the model. In addition to this, the potential issue of multicollinearity among the study variables was examined using the Variance Inflation Factor (VIF), with the results presented in Table 5. The VIF values for all items were found to be well below the commonly accepted threshold of 5, indicating that multicollinearity is not a concern in this model. This outcome confirms that the selected items are appropriately independent, with no evidence of excessively high intercorrelations.

Table 4: HTMT Results.

Variables	CSSP	SIPD	SPDD	SPR
CSSP				
SIPD	0.708			
SPDD	0.692	0.096		
SPR	0.491	0.762	0.749	

Table 5: VIF Results for the Selected Items.

Items	VIF
CSSP1	1.537
CSSP2	1.886
CSSP3	2.139
CSSP4	1.830
SIPD1	1.327
SIPD2	1.729
SIPD3	1.880
SIPD6	1.618
SIPD7	1.874
SIPD8	1.973
SPDD1	1.814
SPDD4	1.801
SPDD5	1.732
SPDD8	1.869
SPR1	1.496
SPR2	1.889
SPR3	1.624
SPR7	1.268

4.3.2. Structural Model Analysis

The structural model was analysed using Smart PLS, which represents a contemporary and advanced method for exploring the relationships among variables within the research framework. This study employed the same analytical approach, with the corresponding results summarised in Table 6. The association between CSSP and SPDD was found to be statistically insignificant, as indicated by a p-value exceeding the 0.05 threshold. The original sample coefficient reflects a weak and negative effect of CSSP on SPDD, with a value of -0.072 and a sample mean of -0.074. The t-statistic was recorded at 1.782, and the p-value of 0.075 confirms the absence of statistical significance. Accordingly, it can be inferred that CSSP does not exert a meaningful influence on SPDD within the current model.

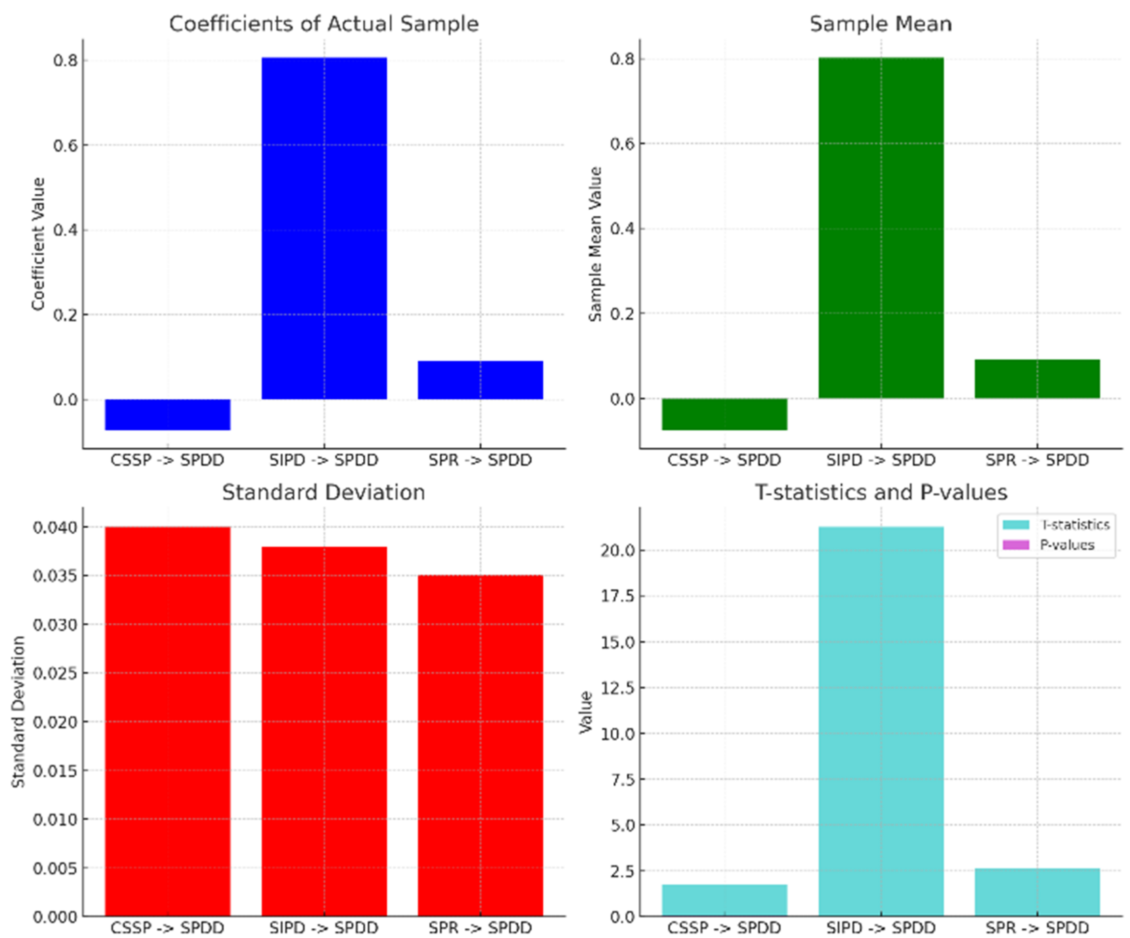

Figure 6: Analysis of SPDD Path Coefficients and Statistics

Conversely, SIPD exhibited a strong and statistically significant positive effect on SPDD. The original sample coefficient was notably high at 0.806, supported by an exceptionally large t-statistic of 21.274 and a p-value of 0.000, which is well below the 0.05 significance level. These findings establish SIPD as a critical determinant of SPDD, underscoring its pivotal role in advancing sustainable product design and development. The relationship between SPR and SPDD was also found to be statistically significant, though its effect size was comparatively modest in relation to that of SIPD. The original sample coefficient for SPR's impact on SPDD was 0.091, indicating a positive but limited influence. This is supported by a t-statistic of 2.633 and a p-value of 0.008, both of which satisfy the criteria for significance at the 5% level. Although the magnitude of the effect is smaller, the results confirm that SPR contributes meaningfully to SPDD, particularly in relation to sustainable product requirements. The corresponding path coefficients and p-values are visually represented in Figure 6, alongside the structural model output generated through Smart PLS 4, as shown in Figure 7.

Table 6: Structural Model Analysis.

Paths Observed	Coefficients of Actual Sample	Sample Mean	Standard Deviation	T-Statistics	P-Values
CSSP -> SPDD	-0.072	-0.074	0.040	1.782	0.075
SIPD -> SPDD	0.806	0.802	0.038	21.274	0.000
SPR -> SPDD	0.091	0.093	0.035	2.633	0.008

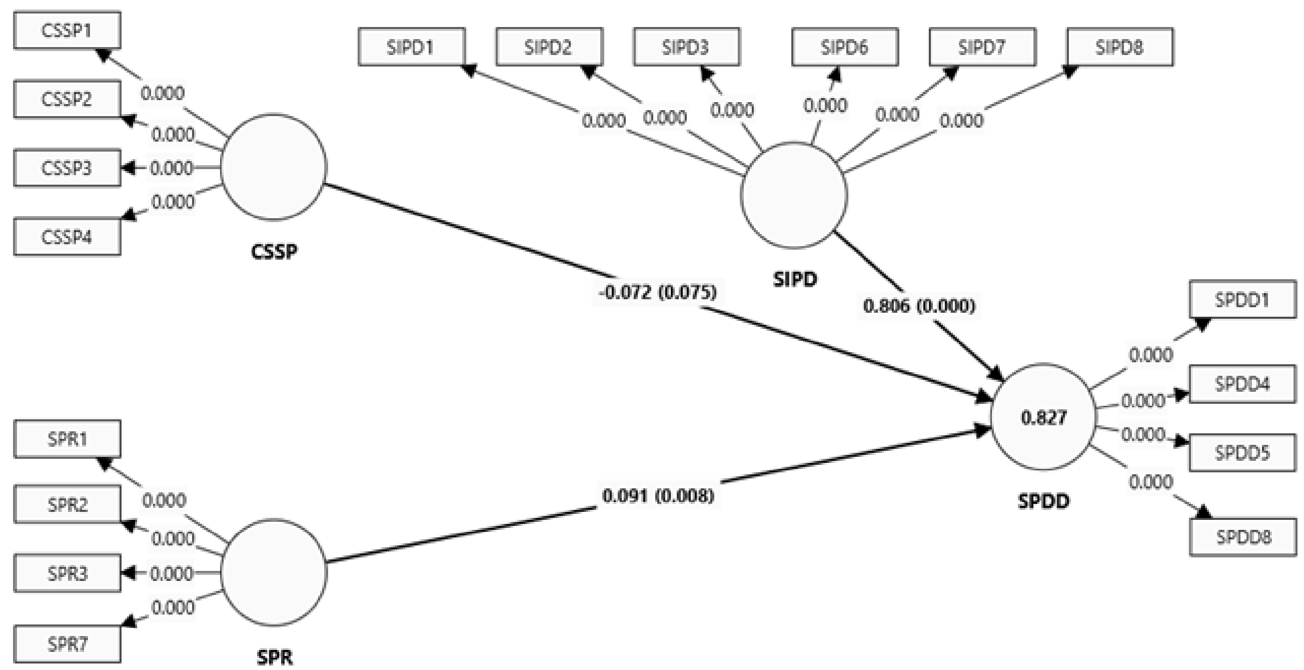

Figure 7: Path Coefficients and P-Values Output using Smart PLS SEM Analysis.

The findings of this study reveal differential impacts of the examined factors on SPDD. Among the three constructs, SIPD emerged as the most influential, demonstrating a strong and statistically significant positive association with SPDD. This outcome underscores the critical importance of incorporating sustainability principles directly within the product development process. Additionally, SPR also showed a significant positive influence on SPDD, although its effect was comparatively weaker than that of SIPD. This indicates that while sustainable product requirements support the design and development process, they do not exert a dominant influence. In contrast, the relationship between CSSP and SPDD was both weak and statistically insignificant, suggesting that this particular path does not contribute meaningfully within the current model and, as such, cannot be accepted. Taken together, the results imply that enhancing SPDD relies primarily on integrating sustainability throughout the product development stages, though there remains a need for broader strategic alignment through improved corporate sustainability policies and strategies.

5. Conclusion

The effective application of product development techniques within business enterprises necessitates routine and continuous evaluation to identify key barriers and implementation gaps. As outlined in the first phase of this study, these techniques comprise: (1) green manufacturing, (2) total quality, (3) value engineering, and (4) computerised production. It is essential that organisations adopt a comprehensive approach in evaluating these techniques, ensuring that none are overlooked. Green manufacturing demands strong commitment from senior management towards environmental protection, focusing on the preservation of vital natural resources such as air, water, and soil, alongside safeguarding employee welfare. Total quality emphasises consistent oversight of operational efficiency and product standards, both internally and externally. The organisation should establish and disseminate general quality policies uniformly across all operational units. Value engineering is aimed at enhancing product and process value, which can be realised through the deployment of skilled personnel, utilisation of high-grade materials, and the optimisation of supplier relationships. The development of in-house manufacturing capabilities for essential materials could further support value engineering, although it would require substantial financial investment. Moreover, the adoption of alternative design strategies is recommended to ensure continuous value enhancement.

Computerised production entails the application of digital technologies across manufacturing, design, and marketing activities. This includes the electronic management of raw materials and inventory systems. For successful implementation, top management must support the integration of such technologies, and employees should receive adequate training in the use of digital tools, particularly in the domains of planning and control. In the second phase, structural model analysis using Smart PLS confirmed that both SIPD and SPR exert a significant and positive influence on SPDD. In light of these findings, it is advised that the company prioritise the integration of sustainability principles throughout all stages of product development. Sustainability should not be treated merely as a design objective, but as a fundamental component embedded across the entire development lifecycle. Concurrently, the organisation should strive to clearly define and align SPR with evolving customer expectations, placing equal emphasis on environmental and social criteria during both design and production phases. This integrated approach will contribute to building a sustainable product portfolio, thereby fostering long-term competitiveness and strategic resilience.

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