ASEAN
Journal of Scientific and Technological Reports
Online ISSN:2773-8752

Academic article

Driving Factors of Remanufacturing Adoption for Diagnostic Radiology Medical Devices in Thailand

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Citation:
Aim-on, P.; Thongpance, N.; Wognkamhan, A.; Nirapai, A. Driving factors of remanufacturing adoption for diagnos radiology medical devices in Thailand. *ASEAN J. Sci. Tech. Report.* **2026**, *29*(12), e265191. https://doi.org/10.55164/ajstr.v29i12.265191

Article history:
Received: April 26, 2026
Revised: July 11, 2026
Accepted: August 16, 2026
Available online: November 7, 2026

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Abstract: Remanufacturing medical devices has become a key strategy for improving resource efficiency, lowering healthcare costs, and promoting a circular economy. Despite this, the integration of remanufactured medical devices into healthcare systems faces obstacles, primarily due to stakeholder acceptance issues. This study aims to create and validate a structural model that explains the factors influencing the adoption of remanufactured diagnostic radiology medical devices in Thailand. The model being studied includes several factors, such as economic considerations, cost, environmental policy, environmental friendliness, attitude, social influence, facilitating conditions, regulatory aspects, quality, and information. Data were collected from a group of 400 experts and professionals involved in medical device management and then analyzed using Structural Equation Modeling (Partial Least Squares Structural Equation Modeling: PLS-SEM). The findings reveal that the majority of the examined factors—including attitude, cost considerations, economic influences, governmental policy, environmental sustainability, social influence, quality, and information availability—exhibited statistically significant correlations with the adoption of medical devices. Conversely, the impact of enabling conditions and regulatory elements was found to be negligible. The model demonstrated a substantial capacity to elucidate the data, explaining 69.5% of the observed variance in adoption behavior ($R^2 = 0.695$). This study contributes to the existing body of knowledge by offering empirical evidence regarding the key determinants that shape the adoption of remanufacturing practices in the medical device sector. Furthermore, the findings provide actionable and policy-relevant recommendations for stakeholders, including policymakers, manufacturers, and healthcare administrators, thus supporting the enduring incorporation of remanufactured medical devices within Thailand's healthcare system.

Keywords: Remanufacturing; medical device; adoption; circular economy

1. Introduction

The medical device industry is one of the high-potential New S-Curve industries that the Thai government has continuously promoted to enhance competitiveness and position Thailand as an international Medical Hub [1]. This policy direction aligns with the growth of the global health economy, which is projected to reach approximately USD 9.8 trillion by 2029 [2]. In addition, the global diagnostic imaging equipment market continues to expand and is expected to reach approximately USD 48.8 billion by Yardi [3].

As the demand for medical devices continues to increase, particularly for high-cost diagnostic radiology equipment such as X-ray, CT, and MRI systems, alternative management approaches have been increasingly considered. One important option is remanufacturing, a process that restores used products to performance levels equivalent to those of new equipment, with comparable warranty conditions. Previous research [4-5] shows that this method can effectively lower production costs and reduce waste. At the same time, it can also improve fair access to healthcare services.

Conversely, Thailand's regulatory environment currently lacks a defined structure to facilitate the trade and utilization of remanufactured medical devices. Consequently, manufacturers are precluded from commercializing these devices, and healthcare providers are denied access to costly equipment at reduced prices. This constraint endures notwithstanding the capacity of Thai manufacturers to remanufacture medical devices in adherence to established safety and performance benchmarks. Furthermore, the absence of such regulatory backing contributes to the disposal of end-of-life or degraded medical devices as electronic waste (e-waste), thereby engendering environmental consequences and resulting in the forfeiture of valuable resources [6].

The Radiological Society of Thailand divides radiological equipment in Thailand into three categories: nuclear medicine, radiation oncology, and diagnostic radiology. Only diagnostic radiology equipment is the subject of this study. (1) X-ray-based imaging modalities, such as General X-ray, Dental X-ray, Mammography, Digital Subtraction Angiography, Computed Tomography, and Fluoroscopy X-ray Machine; and (2) non-X-ray modalities, such as Diagnostic Ultrasound Machine and Magnetic Resonance Imaging Machine systems.

At the same time, the International Electrotechnical Commission (IEC) published IEC 63077, which offers guidelines for best practices in the refurbishment of medical imaging equipment [7]. In addition, several countries have developed regulations to support the standardized use of remanufactured medical devices. These strategies facilitate enhanced access to medical technologies at reduced costs, especially within resource-constrained environments. Consequently, Thailand must cultivate a systematic understanding and endorsement of this methodology by encouraging the utilization of remanufactured medical devices. The diffusion of innovation theory, as articulated by Everett Rogers (1995) [8], provides a useful lens for understanding how innovations are adopted and the factors that shape the acceptance of novel technologies. This theoretical framework allows for the study of user behavior, which then helps in creating effective information-sharing strategies.

The structured application of remanufacturing within the medical equipment sector offers multifaceted advantages, encompassing cost reductions [9], improved healthcare accessibility [10], expanded access to sophisticated technologies [11], and diminished environmental footprints. In addition, this approach aligns with the Circular Economy framework and the BCG (Bio-Circular-Green Economy) model [12], both of which emphasize long-term economic, environmental, and social sustainability [13]. Consequently, a comprehensive investigation into the determinants that promote the remanufacturing of diagnostic radiology medical devices within Thailand is warranted.

2. Literature Review

The investigation, "Factors Promoting the Remanufacturing of Diagnostic Radiology Medical Devices in Thailand," necessitates a theoretical framework to elucidate the individual decision-making processes at play. This entails a comprehensive examination of pertinent concepts, established theories, and prior research, culminating in a synthesis of these viewpoints to pinpoint the determinants that facilitate the remanufacturing of diagnostic radiology medical devices within the Thai context.

2.1 Diagnostic radiology equipment

The Ministry of Public Health has defined 26 radiological instruments or devices [14], and the Radiological Society of Thailand has classified the field of radiology into three specialties: diagnostic radiology, radiation therapy (and oncology), and nuclear medicine [15].

Diagnostic radiology devices are crucial for creating images of internal organs. These images are then used for examinations, treatments, and diagnoses, including the screening of diseases. The devices in question encompass a range of X-ray technologies, including the General X-ray Machine, the Dental X-ray Machine, X-

ray Mammography, Angiography (also known as Digital Subtraction Angiography), the Computed Tomography (CT) Machine, and the Fluoroscopy X-ray Machine. In addition, there are non–X-ray-based devices, including the Diagnostic Ultrasound Machine and the Magnetic Resonance Imaging (MRI) Machine.

According to Market.us Media (Yardi, 2025), the global market for medical imaging equipment is steadily growing, with a projected value of about USD 48.8 billion by Yardi [3].

The COVID-19 pandemic significantly disrupted global healthcare supply chains, mainly because of a shortage of medical equipment. Hospitals faced increased demand for medical devices, and certain types of equipment, which have a modular design and high material costs, are particularly well-suited for remanufacturing [16].

2.1.1 Remanufacturing

Remanufacturing is an industrial process in which used equipment is restored to a level of performance and safety standards at least equivalent to those specified by the original manufacturer, from both consumer and regulatory perspectives. The resulting product must be capable of performing its intended original function and be supported by professional warranty coverage and after-sales services that are no less comprehensive than those provided for a comparable new product [5]. Remanufacturing of medical devices offers benefits to customers, the environment, and manufacturers [17]. The remanufacturing of medical devices demands strict compliance with quality management systems and safety protocols, ensuring that refurbished equipment meets the performance and safety benchmarks established by medical guidelines. Globally, regulatory agencies have established relevant frameworks and regulations. For instance, the European Union Medical Device Regulation (EU MDR) 2017/745 mandates that any modifications or refurbishments of medical devices undergo conformity assessment, risk management, and product traceability procedures before being released into the European market [18]. The U.S. Food and Drug Administration (FDA) requires that any remanufacturing of medical devices, which could affect their safety or how they work, must follow the manufacturer's guidelines. These guidelines are detailed in the Quality System Regulation, specifically 21 CFR Part 820 [19]. Moreover, technical standards, such as those outlined in IEC 63077, guide the refurbishment of medical imaging equipment, thus facilitating the secure reintegration of refurbished devices into clinical environments and their adherence to global standards [7]. In the context of adopting new ideas or technologies in organizations, Rogers' Diffusion of Innovation theory offers a useful explanation. This theory suggests that several factors influence how innovations are adopted [20-21].

2.1.2 Rogers Theory on Diffusion of Innovation

Rogers developed this model to explain the process of innovation diffusion. Diffusion of innovation refers to how a new idea spreads through specific channels to the members of a social system over time. In other words, it is the process through which an innovation spreads from its source of discovery or creation to users or adopters, occurring at the societal level as a group-based process [8]. This process comprises four key elements: the innovation itself, communication through specific channels, acceptance by members of the social system, and the consideration of time. One important factor in the diffusion process is time. In this context, time refers to the period during which an innovation can fully persuade potential adopters until they decide whether to accept or reject the innovation. The innovation-decision process is a linear cognitive process consisting of five stages that individuals (or other decision-making units) undergo: Knowledge, Persuasion, Decision, Implementation, and Confirmation. The adoption of medical technology can be explained through the integration of innovation and technology acceptance frameworks. Previous studies have combined Rogers' Diffusion of Innovation theory with the Technology Acceptance Model (TAM) to examine the factors that influence the adoption of healthcare technologies in medical organizations. These studies found that perceived usefulness and perceived ease of use from TAM, together with innovation attributes from Rogers' framework, effectively explain healthcare professionals' intention to use new technologies. This integrated approach improves understanding of how new technologies are introduced into healthcare systems [22].

2.1.3 Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM) proposed by Fred Davis [23] was developed in the context of information technology system adoption. The model considers external variables that influence individual

perceptions differently, which in turn affect two key constructs: perceived usefulness, which reflects the extent to which information technology enhances performance, and perceived ease of use, which indicates the degree of effort required to use the technology. These two variables influence attitude toward using, which reflects behavioral intention (intention of use) and ultimately leads to actual use. The Technology Acceptance Model (TAM) provides a framework for understanding the adoption of remanufactured goods, positing that the decision to utilize novel technologies or products hinges on their perceived utility and ease of use. Research investigating remanufactured products has employed TAM to assess the determinants of consumer purchase intentions. The results of these studies demonstrate that attitude, perceived usefulness, product knowledge, and perceived risk exert a significant influence on the intention to purchase remanufactured products. These factors are crucial for the success of the circular economy and the adoption of remanufacturing practices in industry [24].

2.2 Conceptual Model

This study proposes factors for promoting the remanufacturing of diagnostic radiology medical devices in Thailand. The expected benefit is to identify key determinants that support the advancement of remanufacturing practices for diagnostic radiology medical devices in the country. Based on the literature review, six groups comprising ten factors were identified. The economic factors include economic considerations and cost. The environmental factors consist of government policy and environmental friendliness. Human factors include attitudes and social influence. Resource factors, on the other hand, involve the physical conditions of the environment. The standard factors include regulations and laws. The technology factors consist of quality and information. The findings of this study are expected to reflect trends and determinants influencing the promotion of remanufacturing for diagnostic radiology medical devices in Thailand. These insights can be used to support policy creation and encourage the long-term growth of the medical device industry.

Hypotheses Development

The hypotheses in this study were developed based on the concept of promoting the remanufacturing of diagnostic radiology medical devices in Thailand. If Thailand aims to advance remanufacturing in this sector, it is necessary to consider the relevant influencing factors. The proposed model is shown in Fig. 1.

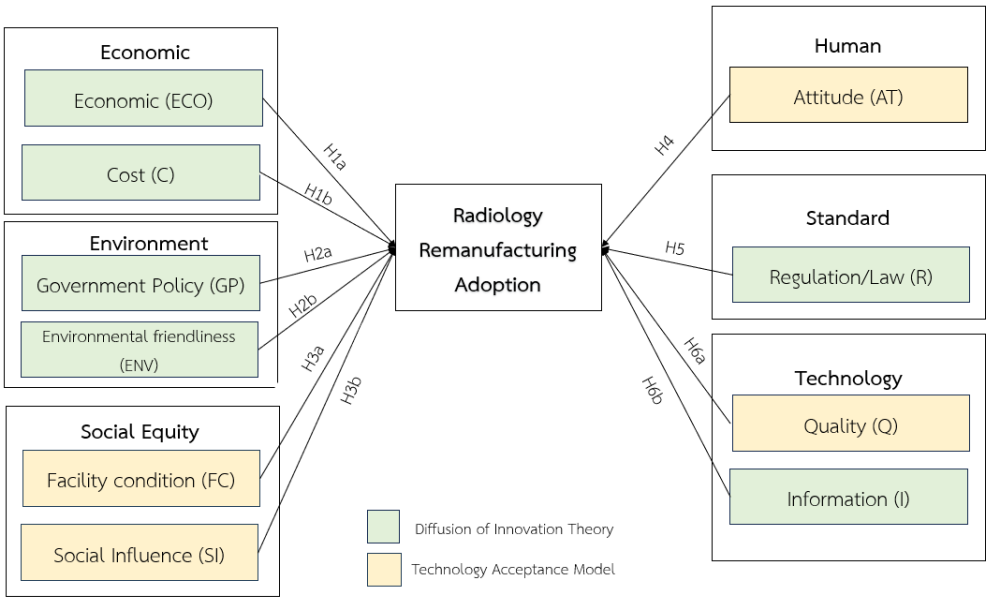


Figure 1. Research Proposed Model

2.2.1 Economic Factors

2.2.1.1 Economic

Remanufacturing presents an economic approach capable of potentially lowering healthcare system costs by restoring products to performance levels comparable to new equipment, albeit at a lower

expense. This approach offers healthcare professionals access to sophisticated technologies, even amidst resource constraints [5]. Furthermore, studies indicate that the implementation of a remanufacturing system can yield enduring financial advantages, contingent upon the application of appropriate cost models and operational methodologies [25]. Incorporating design-for-remanufacturing principles early in the product development process can also enhance competitiveness, boost revenue, and decrease dependence on imports [26]. Furthermore, the implementation of appropriate pricing and quality strategies facilitates the equilibrium of costs and demand. Consequently, remanufactured products can consistently satisfy market requirements, concurrently accounting for the financial constraints inherent within healthcare systems [27].

H1a: Economic factors affect radiology remanufacturing

2.2.1.2. Cost

Economic factors are crucial in encouraging the remanufacturing of diagnostic radiology medical devices; specifically, the remanufacturing process can substantially lower overall expenses relative to acquiring new equipment, potentially yielding cost reductions of 20–50% [28]. Furthermore, the cost structure inherent in remanufacturing reflects effective cost management throughout the entire supply chain, thereby resulting in lower unit production costs compared to new manufacturing and enhancing long-term economic value [27]. From a market standpoint, these cost advantages are also manifested in reduced selling prices, which are significant for user and purchaser acceptance. Studies of consumer behavior suggest that knowledge and awareness of the lower cost associated with remanufactured products directly impact adoption decisions, as they augment perceived value when compared to new products [29].

H1b: Cost affects radiology remanufacturing

2.2.2 Environment Factor

2.2.2.1 Government Policy

Promoting remanufacturing in diagnostic radiology medical devices is consistent with Thailand's 20-Year National Strategy (2018–2037) for sustainable development, which prioritizes environmentally conscious growth. The strategy emphasizes reducing waste, using resources efficiently, and the Bio-Circular-Green (BCG) economic model, all of which are essential for a circular economy. The aim, through the integration of these strategic frameworks, is to optimize resource utilization. This approach seeks to lessen the need for new materials and, crucially, to reduce environmental impact throughout a product's entire lifecycle. In the medical device sector, remanufacturing serves as a practical tool for environmental policy implementation. This is accomplished by extending the operational lifespan of existing equipment, thereby decreasing the need for both raw materials and energy, and consequently, reducing greenhouse gas emissions when compared to the production of new devices. This approach aligns with the principles of a circular economy, which aims to keep resources' value within the economy for as long as possible. Furthermore, sustainability studies have demonstrated that remanufacturing can substantially mitigate resource consumption and environmental consequences [29].

H2a: Government policy affects radiology remanufacturing

2.2.2.2 Environmental friendliness

The perceived environmental advantages of remanufactured goods, including diminished natural resource consumption, reduced energy requirements, and a decrease in both waste production and pollutant emissions, significantly influence stakeholder attitudes and actions. Remanufacturing contributes to the preservation of resource value across a product's lifespan and mitigates environmental consequences relative to new manufacturing processes, thereby supporting sustainability objectives and social responsibility initiatives. Furthermore, the belief that selecting remanufactured goods aids environmental preservation can bolster ethical considerations and foster acceptance within organizations and society as a whole. Consequently, environmental sustainability serves as a crucial element in promoting the proliferation of remanufacturing within healthcare and industrial domains, especially in environments where policy and societal norms prioritize sustainable development [29].

H2b: Environmental friendliness affects radiology remanufacturing

2.2.3 Social Equity Factor

2.2.3.1 Facility Condition

In developing countries, the ability to remanufacture medical devices is significantly influenced by factors related to the facilities. Research indicates that the availability of infrastructure—such as operational space, electrical systems, utilities, laboratories, testing equipment, as well as maintenance and spare parts support systems—is essential for the sustainable use of medical devices [30]. When suitable facilities are lacking, the continuous operation of medical devices is often hindered, even if the equipment has already been purchased. At the same time, studies on adaptive remanufacturing frameworks suggest that flexible facility systems capable of accommodating variations in returned equipment—such as areas for sorting, disassembly, inspection, and performance testing—can improve the efficiency of remanufacturing processes and reduce operational constraints [20]. In addition, the development of local facilities supports technical service systems and spare parts management, reducing dependence on international supply chains and enhancing continuous availability of medical devices within healthcare systems [5].

H3a: Facility Condition affects radiology remanufacturing

2.2.3.2 Social Influence

Social influence significantly affects the adoption and growth of remanufacturing, especially in organizations and industries that deal with complex products. The most important thing is to be confident in the quality and safety of the products. The importance and integration of remanufacturing in product development depend on the perspectives, feelings, and adherence to social norms of different organizational stakeholders. The people involved include executives, engineers, designers, sales teams, and regulatory staff. When remanufacturing is viewed as a secondary activity or simply an operational choice, organizations may struggle to gain the social and strategic support needed for long-term progress. Conversely, developing a shared understanding, recognizing its strategic importance, and promoting a positive view of remanufactured products—both inside and outside the organization—can build confidence, reduce biases related to quality, and encourage wider acceptance. Therefore, social influence is an important external factor that determines how well medical device remanufacturing is accepted and its overall success [26].

H3b: Social influence affects radiology remanufacturing

2.2.4 Human Factor: Attitude

Healthcare professionals, including doctors, biomedical engineers, and healthcare administrators, significantly influence how remanufactured medical devices are used and integrated into practice. Negative perceptions or misconceptions regarding the quality, safety, and reliability of refurbished equipment often pose substantial barriers to their successful deployment. Some people might avoid using these devices, or they might decide they are not working before they actually are, even if they meet the required operational standards. This can lead to wasting resources and making the healthcare system less effective. Conversely, a more comprehensive understanding of systematic remanufacturing methods, including quality standards, safety certifications, and warranty provisions similar to those of new equipment, could positively influence user perceptions and build trust in remanufactured medical devices. Consequently, attitudinal considerations emerge as pivotal determinants of acceptance rates and the efficacy of initiatives aimed at advancing medical device remanufacturing, especially within the context of developing nations, such as Thailand [5], [30].

H4: Attitude affects radiology remanufacturing

2.2.5 Standard Factor: Regulation/Law

Regulatory and legal factors play a critical role in initiating and promoting the remanufacturing of medical devices, as these products are directly related to patient safety and must comply with stringent regulatory standards. The lack of clear legal definitions for remanufacturing, as well as weak or insufficient regulatory frameworks, constitutes a major barrier to building confidence in the quality and safety of remanufactured products [5]. In many contexts, the absence of clear standards and certification mechanisms

leads to remanufacturing being perceived as legally risky, causing both manufacturers and users to avoid adoption. Literature concerning the development of remanufacturing systems suggests that well-defined legal and regulatory structures, including the equal legal standing of remanufacturers and manufacturers, the enforcement of quality management protocols, and the implementation of post-market surveillance, function as facilitators. These frameworks mitigate uncertainty and thereby influence investment choices within remanufacturing systems [24]. Furthermore, bolstering healthcare technology governance, encompassing health technology assessments and systematic medical device management, can improve the secure and sustainable selection, acquisition, and application of remanufactured medical devices [21]. Consequently, regulatory and legal considerations are crucial for the advancement of medical device remanufacturing, especially concerning diagnostic radiology equipment, which necessitates stringent safety and reliability standards.

H5: Regulation/Law affecting radiology remanufacturing

2.2.6 Technology Factor

2.2.6.1 Quality

Quality attributes are essential determinants of acceptance and trust in remanufactured medical devices, especially diagnostic radiology equipment, which is directly linked to patient safety and the precision of diagnoses. Studies suggest that the perceived quality of remanufactured products is a significant concern, given that certain users often perceive these products as inferior to new equipment, even when they have been subjected to inspection, testing, and certification processes adhering to identical standards [29]. Conversely, remanufacturing processes that adhere to explicit engineering standards, incorporate systematic technical performance evaluations, and offer warranty provisions on par with or similar to those of new items can mitigate quality-related uncertainties and bolster user trust [28]. Furthermore, design-for-remanufacturing methodologies emphasize that the incorporation of quality-focused elements during the product design phase—encompassing aspects like disassembly facilitation, component interchangeability, and repeated testing—is crucial for sustaining quality throughout successive life cycles and cultivating a favorable, enduring perception of remanufactured goods [26].

H6a: Quality affects radiology remanufacturing

2.2.6.2 Information

Information-related factors are crucial for the acceptance of remanufactured products. Having and clearly presenting information—like details about the core's condition, its usage and maintenance history, technical specifications, and quality data—is essential. This approach helps reduce uncertainty, which then allows for better planning in remanufacturing [21]. In contrast, a lack of complete or reliable information often leads to risks related to costs, quality, and operational schedules. From both the user's and the market's perspective, providing clear information about the quality, cost savings, and environmental benefits of remanufactured products can reduce perceived risk and create a positive understanding. This, in turn, helps with decision-making and encourages the use of remanufactured products [29]. Therefore, information factors are a key link between operational efficiency and market acceptance of medical device remanufacturing, particularly for diagnostic radiology equipment, which requires reliable data and a high level of trust.

H6b: Information affects radiology remanufacturing

Hypotheses H1 through H6 represent different factors that affect how technology is adopted. These factors include Economic (ECO), Cost (C), Government Policy(GP), Environmental Friendliness (ENV), Facility Condition (FC), Social Influence (SI), Attitude (AT), Regulation/Law (R), Quality (Q), and Information (I). These factors are important in shaping an organization's decisions about adopting and using new technologies.

2.4 Materials and Methods

2.4.1 Research Context

The study, titled "Driving Factors of Remanufacturing Adoption for Diagnostic Radiology Medical Devices in Thailand," included a diverse group of participants. These included medical professionals such as radiologists, radiologic technologists, and biomedical engineers, alongside hospital administrators from both

public and private institutions. Furthermore, the study incorporated representatives from companies engaged in the manufacturing, distribution, and servicing of diagnostic radiology medical devices, as well as regulatory bodies like the Food and Drug Administration. Finally, biomedical engineering researchers and academics were also included. The primary objective was to investigate the factors that facilitate the remanufacturing of diagnostic radiology medical devices within the Thai context, considering various dimensions of the issue.

Furthermore, the findings of this study can be utilized to support the diagnostic radiology medical device industry in Thailand, as well as related industries, by providing insights for promoting remanufacturing practices and facilitating sustainable industrial development.

2.4.2 Data Collection

A total of 400 respondents participated in the survey [31]. The sample size was determined based on the target population that is relevant to the study. The population includes healthcare professionals (radiologists, radiologic technologists, and biomedical engineers), hospital administrators, manufacturers, distributors, and service providers of diagnostic radiology medical devices, and regulatory authorities such as the Food and Drug Administration (FDA) and the Thai Industrial Standards Institute (TISI). According to the Healthcare Accreditation Institute (Public Organization), there are 1,491 public and private hospitals in Thailand. The Thailand Center of Excellence for Life Sciences (Public Organization) reported that 933 companies are engaged in the production, distribution, and maintenance of medical devices. Together with two relevant regulatory agencies, the total number of organizations associated with the study was estimated at 2,426. Assuming an average of 15 relevant personnel per organization, the total target population was estimated to be 36,390 individuals. The sample size was calculated using Yamane's formula [31] with a 95% confidence level and a margin of error of 5%, resulting in a minimum required sample size of 400 respondents. Data were collected through a convenience sampling technique. Questionnaires were distributed to available and willing eligible participants to participate in the study until the required sample size was reached. The inclusion of participants from multiple organizational roles enabled a comprehensive reflection of factors promoting the remanufacturing of diagnostic radiology medical devices in Thailand. The questionnaire was structured around six main constructs comprising ten factors: economic, cost, government policy, environmental friendliness, attitude, social influence, facility condition, regulation/law, quality, and information. The Ethics Review Board of Rangsit University granted ethical approval for this research (Certificate No. RSU-ERB2026/020.2001). Participation was voluntary, and the confidentiality of all responses was maintained throughout the study.

2.4.3 Measurement Validity and Reliability

The analysis showed that the constructs were internally consistent. The Cronbach's alpha values, ranging from 0.815 to 0.924, were above the recommended threshold [32]. To assess convergent and discriminant validity, Measurement Model Assessment was used. The Average Variance Extracted (AVE) was used to evaluate convergent validity, while the Fornell–Larcker criterion and the Heterotrait–Monotrait ratio (HTMT) were used to assess discriminant validity [33]. Furthermore, the analysis showed no signs of multicollinearity. The Variance Inflation Factor (VIF) values were clearly below the acceptable threshold of 5 [34].

2.4.4 Data Analysis

To evaluate the relevance of indicators and path coefficients, the study utilized SmartPLS Version 4.0.9 with a Bootstrapping method, as recommended by Hair Jr. et al. [35]. This analysis was conducted on 5,000 sub-samples. The relationships in the structure were tested by means of SEM using SmartPLS [36], which is an appropriate technique for testing complex behavioral models that include latent variables and indirect effects. Path coefficients, t-values, and significance levels were used to evaluate the structural paths.

3. Results and Discussion

3.1 Results

3.1.1 Demographic Data of Respondents

The demographic data showed a fairly balanced gender distribution among the participants. Specifically, women made up 53.75% of the sample, while men made up 46.25%. This indicates that both genders were represented in the study. Regarding employment, most respondents worked in the public sector (51.00%), followed by those in the private sector (47.00%). A small number (2.00%) reported being self-employed. Table 1 provides a detailed look at how technology is accepted and new methods are used in organizations, covering both public and private sectors.

Table 1. Demographic Data of Respondents

Item	Demographic Information	Amount	%
Gender	Male	185	46.25
	Female	215	53.75
Age	18–25 years	100	25.00
	26–35 years	98	24.50
	36–45 years	70	17.50
	46-55 years	68	17.00
	56-60 years	64	16.00
Education Level	Diploma	20	5.00
	Bachelor	295	73.75
	Master	65	16.25
	PhD.	20	5.00
Occupation	Government officer	204	51.00
	Business owner	8	2.00
	Employee	188	47.00
Job Position	Radiologic Technologist	226	56.50
	Biomedical Engineer	74	18.50
	Engineer	16	4.00
	Managing Director	16	4.00
	Industrial Technical Officer	16	4.00
	Public Health Officer	16	4.00
	Technician	12	3.00
	Radiographer Technician	8	2.00
	Nurse Anesthetist	8	2.00
	University Lecturer	8	2.00

3.1.2 Construct Reliability and Validity

Cronbach's Alpha and Composite Reliability (CR) were calculated, with values ranging from 0.815 to 0.946, indicating a high and acceptable level of internal consistency for subsequent analysis [37]. In addition, the Average Variance Extracted (AVE) ranged from 0.561 to 0.853 [38], as presented in Table 2.

Table 2. Construct Reliability and Validity

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
AT	0.895	0.898	0.927	0.762
C	0.902	0.931	0.927	0.719
ECO	0.898	0.913	0.923	0.706
ENV	0.906	0.909	0.930	0.727
FC	0.924	0.969	0.945	0.811
GP	0.906	0.931	0.931	0.730
I	0.914	0.916	0.946	0.853
Q	0.915	0.920	0.940	0.798
R	0.924	0.938	0.946	0.814
SI	0.815	0.827	0.864	0.561

3.1.3 Fornell-Larcker Criterion

Table 3 presents the results of the discriminant validity assessment using the Fornell–Larcker criterion. The square root of the Average Variance Extracted (AVE) for each construct, located on the diagonal of the matrix, is greater than the correlations with other constructs in the same row and column. This indicates that each construct is distinct, meaning it shares more variance with its own indicators than with other constructs in the model. Therefore, the model shows adequate discriminant validity, as determined by the Fornell and Larcker criterion [39].

Table 3. Fornell-Larcker Criterion

	ADOPTION	AT	C	ECO	ENV	FC	GP	I	Q	R	SI
ADOPTION	1.000										
AT	0.748	0.873									
C	0.583	0.570	0.848								
ECO	0.476	0.585	0.778	0.841							
ENV	0.579	0.711	0.549	0.593	0.853						
FC	0.461	0.452	0.427	0.454	0.585	0.901					
GP	0.637	0.734	0.616	0.755	0.786	0.557	0.854				
I	0.447	0.440	0.434	0.556	0.543	0.711	0.551	0.923			
Q	0.642	0.625	0.435	0.447	0.632	0.764	0.592	0.782	0.893		
R	0.469	0.432	0.313	0.431	0.429	0.673	0.551	0.737	0.817	0.902	
SI	0.419	0.562	0.509	0.555	0.593	0.756	0.614	0.763	0.660	0.601	0.749

To evaluate the possibility of multicollinearity among the indicators, the Variance Inflation Factor (VIF) was analyzed. The findings reveal that VIF values for all constructs span from 1.000 to 4.730, all of which are below the suggested cut-off of 5.0. Consequently, these results imply that multicollinearity does not present a significant issue within the model. Therefore, each indicator adequately explains its corresponding latent construct, and the model is appropriate for subsequent structural model analysis [32].

3.1.4 Heterotrait-Monotrait ratio (HTMT).

Table 4 shows the results of the Heterotrait-Monotrait Ratio (HTMT) test for the assessment of discriminant validity. The HTMT values varied from 0.328 to 0.896. The results indicated that most of the HTMT values were below the recommended cut-off of 0.85. However, five pairings of constructs, GP–ENV (0.858), Q–I (0.855), SI–FC (0.896), SI–I (0.859), and R–Q (0.888), were above this level. These findings may imply possible issues of discriminant validity among these construct dyads. However, all the HTMT values were below the more liberal threshold of 0.90, which suggests that the measuring model presents an acceptable level of discriminant validity in general, although caution should be taken when interpreting the correlations between these specific constructs.

Table 4. Heterotrait-Monotrait ratio (HTMT).

ADOPTION	AT	C	ECO	ENV	FC	GP	I	Q	R	SI
AT	0.788									
C	0.593	0.606								
ECO	0.483	0.637	0.841							
ENV	0.603	0.783	0.596	0.643						
FC	0.453	0.476	0.465	0.499	0.636					
GP	0.655	0.806	0.657	0.832	0.858	0.613				
I	0.467	0.482	0.475	0.617	0.594	0.764	0.600			
Q	0.669	0.685	0.465	0.493	0.688	0.814	0.640	0.855		
R	0.482	0.468	0.328	0.472	0.459	0.706	0.592	0.800	0.888	
SI	0.405	0.612	0.594	0.640	0.683	0.896	0.714	0.859	0.734	0.660

3.1.5 Results of The Structural Model

The structural model analysis, as shown in Table 4, aimed to identify the factors influencing the adoption of remanufacturing for diagnostic radiology medical devices in Thailand. The results indicate that several factors have a statistically significant effect on the adoption of remanufacturing.

Table 4. Results of the Structural Model

Hypothesis	Path	Path Coefficient	t-value	p-value	Decision
H1a	ECO -> ADOPTION	-0.306	4.695	0.000	Supported
H1b	C -> ADOPTION	0.382	7.731	0.000	Supported
H2a	GP -> ADOPTION	0.290	4.204	0.000	Supported
H2b	ENV -> ADOPTION	-0.134	2.242	0.025	Supported
H3a	FC -> ADOPTION	0.075	1.200	0.230	Not Supported
H3b	SI -> ADOPTION	-0.313	4.960	0.000	Supported
H4	AT -> ADOPTION	0.518	7.817	0.000	Supported
H5	R -> ADOPTION	-0.020	0.269	0.788	Not Supported
H6a	Q -> ADOPTION	0.269	3.802	0.000	Supported
H6b	I -> ADOPTION	0.126	2.362	0.018	Supported

3.1.6 Model Fit

The average AVE and R^2 values were 0.748 and 0.695, respectively, indicating good convergent validity and good explanatory power of the structural model. These results indicate that the latent constructs adequately explain the variance of their respective indicators and that the model is able to explain a substantial amount of variance in the endogenous variables. Furthermore, the Q^2 value of 0.674 was above the recommended cut-off of zero, indicating strong predictive relevance and confirming the model's predictive power of the observed data. The overall goodness-of-fit (GoF) index was 0.721, which was significantly greater than the recommended threshold of 0.36, thus indicating a robust overall model fit. This outcome shows that the proposed model provides a satisfactory representation of the relationships among the constructs under investigation. The standardized root mean square residual (SRMR) value was 0.089, slightly higher than the commonly recommended cut-off value of 0.08, but the difference was negligible. Considering the high GoF, R^2, and Q^2 values, the overall model fit can still be regarded as acceptable for further structural model analysis.

$$GoF = \sqrt{\overline{R^2} \times \overline{AVE}} = \sqrt{0.695 \times 0.748} = 0.721 \quad (1)$$

Table 5. Oodness-of-Fit (GoF) Measurement.

Latent Variable	Average Variance Extracted (AVE)	R square	Q^2
AT	0.762		
C	0.719		
ECO	0.706		
ENV	0.727		
FC	0.811		
GP	0.730		
I	0.853		
Q	0.798		
R	0.814		
SI	0.561		
Average	0.748	0.695	0.674

From Table 5. Presents the overall model fit results, including the Goodness of Fit (GoF), R^2, and Q^2 values. The average AVE is 0.748, the average R^2 is 0.695, and the average Q^2 is 0.674. The data analysis shows a strong connection between adoption and several important factors. These include Economic factors, Cost, Government Policy, Environmental Friendliness, Attitude, Social Influence, Quality, and Information, all of

which had p-values below 0.05 [40]. This suggests that these factors are important in influencing the adoption of remanufacturing for medical devices in Thailand. In other words, perceptions related to attitude, cost, economic considerations, environmental factors, government policy, innovation-related infrastructure, quality, and social influence all contribute to supporting and shaping the acceptance of this technology.

Conversely, Facility Condition and Regulation/Law did not demonstrate statistically significant impacts on adoption, given that their p-values surpassed the 0.05 threshold. This suggests that these two elements are not substantial determinants of technology adoption behavior within the context of the proposed research model.

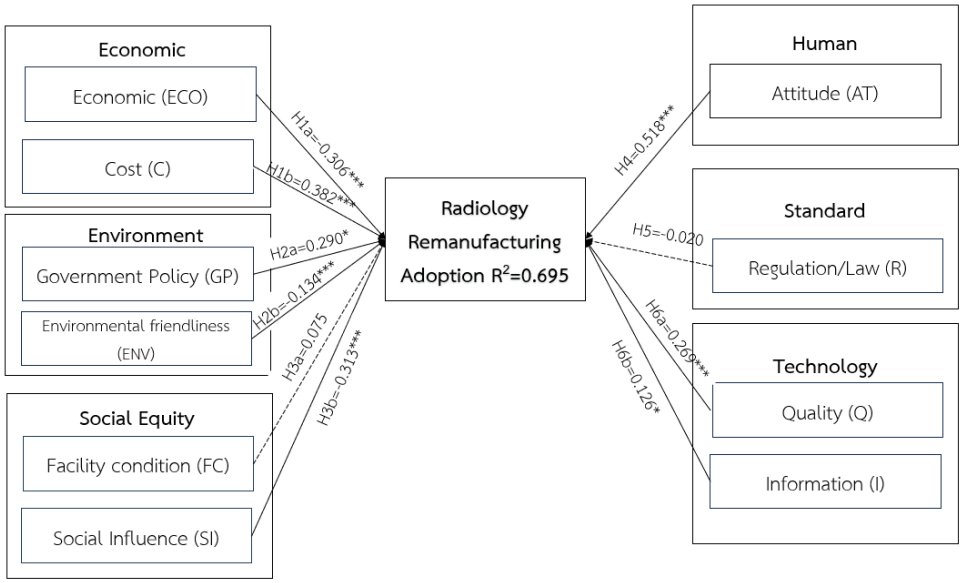


Figure 2. Results of The Structural Model
Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The most significant connection within the model is the one between ATTITUDE and Adoption; this is supported by a path coefficient of 0.518 and a p-value below 0.05. This suggests that users' attitudes are crucial in determining whether remanufactured medical devices are adopted in healthcare settings. The model accounts for 69.5% of the variance in the factors that encourage the remanufacturing of diagnostic radiology medical devices within Thailand. This finding suggests a considerable degree of explanatory power, as assessed by benchmarks in behavioral and technology adoption studies [41]. Therefore, the model seems well-suited for understanding the factors that influence the adoption of remanufacturing technology in Thailand.

3.2 Discussion

This investigation seeks to examine the determinants affecting the uptake of remanufactured diagnostic radiology medical devices within Thailand, employing Structural Equation Modeling (SEM) as its methodological framework. The findings suggest that a variety of factors, encompassing economic, environmental, human, resource, standard, and technological dimensions, significantly influence the decision-making process regarding the adoption of remanufacturing technology. The factors being examined include Economic and Cost (economic dimension); Government Policy and Environmental Friendliness (environmental dimension); Attitude and Social Influence (human dimension); Facility Condition (resource dimension); Regulation/Law (standard dimension); and Quality and Information (technological dimension). The findings reveal that Attitude, Cost, Economic, Environmental Friendliness, Government Policy, Information, Quality, and Social Influence are significantly associated with adoption ($p < 0.05$), whereas Facility Condition and Regulation/Law are not statistically significant ($p > 0.05$). In addition, the model explains 69.5% of the variance in technology adoption ($R^2 = 0.695$), indicating a relatively high level of explanatory power for research in behavioral and technology adoption

3.2.1 Economic Factor

3.2.1.1 Economic

The data indicate a statistically significant relationship between economic factors and the adoption of remanufacturing ($p < 0.05$). This suggests that economic considerations significantly influence decisions about technology adoption in healthcare systems. Remanufacturing offers a financially beneficial method for reducing costs in the healthcare system. This is achieved by restoring products to performance levels similar to new equipment, but at a lower cost. This enables healthcare providers to access medical technologies more broadly under budget constraints [5]. Moreover, previous studies suggest that a remanufacturing system can generate long-term economic value, assuming that suitable cost models and operational processes are used [24]. The negative effects of the economic (ECO) perspective can be explained by the characteristics of the respondents. Most of the participants were technical staff, not organizational executives, and therefore economic factors such as investment costs, financial returns, or long-term profitability were not much considered. Instead, respondents primarily assessed the operational benefits, usability, and functionality of remanufactured medical devices. The reduced importance of economic factors may explain the negative correlation between the economic perspective and intention to adopt remanufactured medical devices.

3.2.1.2 Cost

The findings reveal a significant correlation between cost considerations and adoption rates ($p < 0.05$), implying that economic benefits are a primary driver in the uptake of remanufactured medical devices. Prior research has demonstrated that remanufacturing can yield cost reductions of roughly 20–50% relative to the acquisition of new equipment [27]. This economic advantage, in turn, increases overall value and facilitates more efficient resource allocation within healthcare systems.

3.2.2 Environment Factor

3.2.2.1. Government Policy

The results show a statistically significant relationship between government policies and the use of remanufacturing practices, with a p-value below 0.05. This observation aligns with Thailand's 20-Year National Strategy and the circular economy framework, both of which prioritize resource efficiency and waste minimization. By remanufacturing medical devices, we can keep them in use longer. This, in turn, decreases the demand for fresh raw materials and lessens the strain on the environment. These benefits align with Thailand's current focus on a Bio-Circular-Green (BCG) Economy Model.

3.2.2.2 Environmental Friendliness

The results indicate a statistically significant correlation between environmental considerations and the adoption of remanufacturing practices ($p = 0.025$). The idea that remanufacturing helps protect natural resources, reduce waste, and lessen environmental damage strengthens the argument for its use in healthcare. The negative effect of Environmental Friendliness (ENV) might be attributed to the respondents' priorities when assessing remanufactured medical devices. While environmental sustainability is generally recognized to be important, respondents tended to place a higher value on product quality, safety, reliability, and clinical performance than environmental benefits. Thus, environmental friendliness was not regarded as a significant predictor of their intention to use remanufactured medical devices, resulting in the negative association observed.

3.2.3 Social Equity Factor

3.2.3.1 Facility Condition

The data indicate that the state of the facility doesn't have a statistically significant relationship with technology adoption ($p = 0.23$). This finding might be explained by the study's focus on adoption, which measures the actual use of technology. Most of the survey participants were direct users of medical devices, rather than those responsible for financial decisions or infrastructure within their organizations.

Therefore, the perceived readiness of facilities, utilities, or supporting infrastructure might not directly affect the decision to use remanufactured medical devices. Moreover, the people involved usually

do not directly participate in buying things or building facilities. This lack of direct involvement might explain why this particular factor did not have a statistically significant effect in the research model.

3.2.3.2 Social Influence

The results indicate that social influence is significantly associated with adoption ($p < 0.001$). The perceptions and attitudes of stakeholders—such as administrators, engineers, and healthcare personnel—can influence technology adoption at the organizational level. When organizational policies and culture support remanufacturing, the likelihood of it being widely used increases. The negative effect of social influence (SI) is due to the decision-making process in the healthcare sector. In general, peers' or colleagues' recommendations or opinions do not influence the decision to adopt remanufactured medical devices but rather clinical performance, safety standards, technical specifications, and regulatory compliance. A possible explanation for the negative relationship observed is that respondents seemed to give more weight to objective professional judgment rather than social influence in assessing remanufactured medical devices.

3.2.4 Human Factor: Attitude

The results indicate that attitude is significantly associated with adoption ($p < 0.001$) and represents the strongest factor in the model. The attitudes of healthcare personnel—such as physicians, biomedical engineers, and technical staff—play a crucial role in the decision to adopt remanufactured medical devices. When personnel have confidence in the quality and safety of the equipment, the likelihood of technology acceptance increases.

3.2.5 Standard Factor: Regulation/Law

The data suggest that regulatory and legal considerations do not exhibit a statistically significant relationship with technology adoption ($p = 0.788$). This observation could be interpreted as indicating that medical device users view regulatory adherence as the purview of regulatory bodies or purchasing divisions, rather than a determinant of operational choices regarding technology utilization.

3.2.6 Technology Factor

3.2.6.1 **Quality**

The findings demonstrate a significant correlation between quality factors and adoption ($p < 0.001$). Specifically, the perceived quality and reliability of remanufactured medical devices emerge as crucial determinants of user confidence, especially concerning diagnostic radiology equipment, which necessitates elevated standards of both accuracy and safety.

3.2.6.2 Information

The results indicate that information factors are significantly associated with adoption ($p = 0.018$). The availability of information—such as usage history, maintenance records, and technical specifications—plays an important role in reducing uncertainty and increasing confidence in the decision to adopt remanufactured medical devices.

4. Conclusions

This research proposed and then tested a structural model to explain the factors influencing the adoption of remanufacturing for diagnostic radiology medical devices in Thailand, using Structural Equation Modeling (SEM). The findings show that the adoption of this technology is not driven by a single factor. Instead, it is the result of the interaction of several different aspects, including economic, environmental, human, resource, standard, and technological factors. The results show that most factors in the model—Economic, Cost, Government Policy, Environmental Friendliness, Attitude, Social Influence, Quality, and Information—are significantly associated with adoption. Conversely, Facility Condition and Regulation/Law did not demonstrate statistical significance. This finding could be attributed to the composition of the survey population, which primarily consisted of individuals who directly utilize medical devices. For these users, the device's operational efficacy, user-friendliness, and general quality frequently represent the most critical considerations. In contrast, factors like infrastructure readiness and regulatory compliance, which are usually handled by administrators or regulatory bodies, are less important to them. Furthermore, the analysis

indicates that user attitudes are the most important factor in adopting remanufacturing technology. Cost, quality, government policy, and social influence also play important roles. Therefore, these findings underscore the importance of how users perceive, trust, and understand new technologies when deciding whether to use them in healthcare. The model explains 69.5% of the variation in the adoption of remanufactured diagnostic radiology medical devices in Thailand ($R^2 = 0.695$). This suggests that research on the adoption of behavioral technology is quite effective in explaining this phenomenon. The study's conclusions hold significance for both scholarly inquiry and practical application. From an academic standpoint, the research contributes to the existing body of knowledge regarding the determinants that facilitate the integration of remanufacturing within healthcare infrastructures. Consequently, the findings furnish practical guidance for a diverse array of stakeholders, including policymakers, technological pioneers, manufacturers of medical devices, and healthcare administrators, thereby assisting them in crafting strategies to facilitate the effective deployment of remanufacturing technologies. These strategies include building consumer trust in product quality, improving access to relevant information, creating strong support systems, and developing user understanding and educational programs. In future research, the results of this study should be extended to include a comparison of factors leading to acceptance in other nations, which would shed greater light on the role of national context in the adoption of remanufactured diagnostic radiological medical devices. Future studies should also broaden the target audience to include stakeholders at all levels of the organization and use longitudinal methodologies to track changes in the factors influencing adoption over time. A broader scope would promote the development of a more comprehensive knowledge of the factors influencing the adoption of remanufacturing technologies and their contribution to sustainable management of medical technologies and the development of the circular economy.

5. Acknowledgments

The author expresses sincere gratitude to all medical device professionals, healthcare personnel, and related experts. Their generous contributions of time, information, and the completion of questionnaires were essential to this study. The data and experiences shared by all participants were crucial, forming the foundation that enabled the successful completion of this research and the achievement of its objectives. The author expresses gratitude to all reviewers and contributors for their helpful comments and suggestions, which greatly improved and strengthened this research.

Author Contributions: Conceptualization, P.A. and A.N.; methodology, P.A. and A.N.; formal analysis, P.A. and A.N.; investigation, P.A.; data curation, P.A.; writing—original draft preparation, P.A.; writing—review and editing, A.N., N.T. and A.W.; visualization, P.A.; supervision, N.T. and A.N.; project administration, A.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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Appendix

Abbr.	Measurement items	Mean	S.D.	Loading (>0.70)	Outer VIF (<5.00)	Source
Economic Factors (ECO)						
ECO1	Remanufacturing helps improve the efficiency of economic resource utilization	4.300	0.608	0.838	2.358	Singh, R. K., Murty, H. R., Gupta, S. K., & Dikshit, A. K. (2009). An overview of sustainability assessment methodologies. Ecological Indicators, 9(2), 189–212. https://doi.org/10.1016/j.ecolind.2008.05.011
ECO2	Effective remanufacturing management contributes to long-term stability and sustainability.	4.218	0.644	0.843	2.338	Dyllick, T., & Hockerts, K. (2002). Beyond the business case for corporate sustainability. Business Strategy and the Environment, 11(2), 130–141. https://doi.org/10.1002/bse.323
ECO3	Remanufacturing enhances economic competitiveness.	4.060	0.705	0.795	2.606	Porter, M. E., & van der Linde, C. (1995). Toward a new conception of the environment–competitiveness relationship. Journal of Economic Perspectives, 9(4), 97–118. https://doi.org/10.1257/jep.9.4.97
ECO4	Investment in remanufacturing improves economic efficiency.	4.147	0.656	0.890	3.124	Schumpeter, J. A. (1934). The theory of economic development. Harvard University Press.
ECO5	Remanufacturing can mitigate the impacts of market fluctuations.	3.955	0.709	0.834	2.227	Brigham, E. F., & Ehrhardt, M. C. (2016). Financial management: Theory & practice (15th ed.). Cengage Learning.
Cost Factors (C)						
C1	Remanufacturing helps reduce long-term costs.	4.180	0.712	0.877	2.725	Zhu, Q., & Sarkis, J. (2004). Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises. Journal of Operations Management, 22(3), 265–289. https://doi.org/10.1016/j.jom.2004.01.005

Abbr.	Measurement items	Mean	S.D.	Loading (>0.70)	Outer VIF (<5.00)	Source
C2	The use of automation technologies in remanufacturing processes helps reduce labor costs.	4.077	0.870	0.712	1.745	Ijomah, W. L., McMahon, C. A., Hammond, G. P., & Newman, S. T. (2007). Development of design for remanufacturing guidelines to support sustainable manufacturing. Robotics and Computer-Integrated Manufacturing, 23(6), 712–719. https://doi.org/10.1016/j.rcim.2007.02.017
C3	Remanufacturing helps reduce the costs associated with purchasing new machinery or equipment.	4.237	0.779	0.903	3.313	Lund, R. T. (1984). Remanufacturing: The experience of the United States and implications for developing countries. World Bank Technical Paper No. 31.
C4	Reusing remanufactured components helps reduce raw material costs.	4.180	0.684	0.904	3.325	Gray, C., & Charter, M. (2007). Remanufacturing and product design: Designing for the 7th generation. The Centre for Sustainable Design, UK.
C5	Remanufacturing helps reduce expenses related to waste disposal and end-of-life materials.	4.178	0.715	0.828	2.504	Sundin, E., & Bras, B. (2005). Making functional sales environmentally and economically beneficial through product remanufacturing. Journal of Cleaner Production, 13(9), 913–925. https://doi.org/10.1016/j.jclepro.2004.04.006
Government Policy Factors (GP)						
GP1	Government policies play a significant role in promoting remanufacturing practices and encouraging industries to adopt circular economy principles.	4.003	0.75	0.735	2.037	Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation & Recycling, 127, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005
GP2	Government remanufacturing policies help reduce the environmental impacts associated with industrial waste.	4.197	0.751	0.908	3.780	Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The circular economy – A new sustainability paradigm? Journal of Cleaner Production, 143, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Abbr.	Measurement items	Mean	S.D.	Loading (>0.70)	Outer VIF (<5.00)	Source
GP3	Domestic environmental regulations encourage manufacturers to develop environmentally friendly remanufacturing processes.	4.178	0.701	0.863	2.656	Bansal, P., & Roth, K. (2000). Why companies go green: A model of ecological responsiveness. Academy of Management Journal, 43(4), 717–736. https://doi.org/10.5465/1556363
GP4	The enforcement of environmental and remanufacturing regulations motivates organizations to develop cleaner and more sustainable technologies.	4.290	0.683	0.904	3.427	Rennings, K. (2000). Redefining innovation—eco-innovation research and the contribution from ecological economics. Ecological Economics, 32(2), 319–332. https://doi.org/10.1016/S0921-8009(99)00112-3
GP5	Incorporating remanufacturing into government environmental policies enhances an organization's social image and reputation.	4.067	0.740	0.849	2.731	Darnall, N., Henriques, I., & Sadorsky, P. (2008). Do environmental management systems improve business performance in an international setting? Journal of International Management, 14(4), 364–376. https://doi.org/10.1016/j.intman.2007.09.006
Environmental friendliness Factors (ENV)						
ENV1	Remanufacturing helps reduce waste generation and environmental pollution.	4.065	0.807	0.876	4.074	Hart, S. L. (1995). A natural-resource-based view of the firm. Academy of Management Review, 20(4), 986–1014. https://doi.org/10.5465/amr.1995.9512280033
ENV2	Remanufactured products are designed to minimize environmental impacts throughout their life cycle.	4.035	0.815	0.856	3.405	Pigosso, D. C., Rozenfeld, H., & McAloone, T. C. (2013). Ecodesign maturity model: A management framework to support ecodesign implementation into manufacturing companies. Journal of Cleaner Production, 59, 160–173. https://doi.org/10.1016/j.jclepro.2013.06.040
ENV3	Remanufacturing emphasizes the procurement of raw materials from sustainable and environmentally responsible sources.	4.210	0.697	0.836	2.435	Min, H., & Galle, W. P. (2001). Green purchasing practices of US firms. International Journal of Operations & Production Management, 21(9), 1222–1238. https://doi.org/10.1108/EUM0000000005923

Abbr.	Measurement items	Mean	S.D.	Loading (>0.70)	Outer VIF (<5.00)	Source
ENV4	Remanufacturing promotes environmental awareness and environmentally responsible behavior.	4.175	0.758	0.847	2.496	Daily, B. F., & Huang, S. (2001). Achieving sustainability through attention to human resource factors in environmental management. International Journal of Operations & Production Management, 21(12), 1539–1552. https://doi.org/10.1108/01443570110410892
ENV5	Remanufacturing positively influences customer perceptions and trust.	4.015	0.851	0.848	2.536	Chen, Y. S. (2010). The drivers of green brand equity: Green brand image, green satisfaction, and green trust. Journal of Business Ethics, 93(2), 307–319. https://doi.org/10.1007/s10551-009-0223-9
Facility Condition Factor (FC)						
FC1	Workplace facilities are well maintained and support efficient remanufacturing operations.	3.938	0.777	0.917	3.490	Hameed, A., & Amjad, S. (2009). Impact of office design on employees' productivity: A case study of banking organizations of Abbottabad, Pakistan. Journal of Public Affairs, Administration and Management, 3(1), 1–13.
FC2	Information technology systems effectively support the monitoring and control of remanufacturing processes.	4.020	0.710	0.937	4.198	Lee, J., Bagheri, B., & Kao, H. A. (2015). A cyber-physical systems architecture for industry 4.0-based manufacturing systems. Manufacturing Letters, 3, 18–23. https://doi.org/10.1016/j.mfglet.2014.12.001
FC3	An effective equipment maintenance system supports the continuous operation of remanufacturing processes.	4.037	0.875	0.894	3.816	Wireman, T. (2004). Total productive maintenance. Industrial Press.
FC4	The quality of facilities and infrastructure contributes to the efficiency and sustainability of remanufacturing operations.	4.030	0.857	0.851	2.955	Dyllick, T., & Hockerts, K. (2002). Beyond the business case for corporate sustainability. Business Strategy and the Environment, 11(2), 130–141. https://doi.org/10.1002/bse.323

Abbr.	Measurement items	Mean	S.D.	Loading (>0.70)	Outer VIF (<5.00)	Source
Social Influence Factor (SI)						
SI1	People who are important to me support the use of remanufacturing practices.	3.942	0.860	0.677	2.183	Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. MIS Quarterly, 27(3), 425–478. https://doi.org/10.2307/30036540
SI2	People around me expect me to adopt remanufacturing practices.	3.855	0.802	0.756	1.446	Ajzen, I. (1991). The theory of planned behavior. Organizational Behavior and Human Decision Processes, 50(2), 179–211. https://doi.org/10.1016/0749-5978(91)90020-T
SI3	Communication and information regarding remanufacturing influence my decision to adopt it.	4.110	0.776	0.833	2.510	Rogers, E. M. (2003). Diffusion of innovations (5th ed.). Free Press.
SI4	Recommendations from colleagues or experts influence my decision to use remanufacturing practices.	4.030	0.703	0.732	1.485	Kelman, H. C. (1958). Compliance, identification, and internalization: Three processes of attitude change. Journal of Conflict Resolution, 2(1), 51–60. https://doi.org/10.1177/002200275800200106
SI5	Organizational and societal culture encourages the continuous adoption of remanufacturing practices.	3.940	0.873	0.739	2.326	Hofstede, G. (2001). Culture's consequences: Comparing values, behaviors, institutions, and organizations across nations (2nd ed.). Sage Publications.
Attitude Factor (AT)						
AT1	I have a positive attitude toward changes associated with remanufacturing.	4.190	0.731	0.816	2.054	Venkatesh, V., Thong, J. Y. L., & Xu, X. (2012). Consumer acceptance and use of information technology: Extending the unified theory of acceptance and use of technology. MIS Quarterly, 36(1), 157–178.
AT2	Remanufacturing can improve work efficiency.	4.008	0.795	0.860	2.679	Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. Management Science, 46(2), 186–204. https://doi.org/10.1287/mnsc.46.2.186.11926

Abbr.	Measurement items	Mean	S.D.	Loading (>0.70)	Outer VIF (<5.00)	Source
AT3	I intend to continue using remanufacturing practices in the future.	4.210	0.683	0.912	4.183	Fishbein, M., & Ajzen, I. (1975). Belief, attitude, intention, and behavior: An introduction to theory and research. Addison-Wesley.
AT4	Remanufacturing is essential for the future development of organizations.	4.128	0.704	0.900	4.571	Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. Management Science, 35(8), 982–1003. https://doi.org/10.1287/mnsc.35.8.982
Regulation/Law Factor (R)						
R1	Clear legal requirements enable organizations to implement remanufacturing processes correctly and safely.	4.192	0.749	0.864	2.440	Steinhilper, R. (1998). Remanufacturing: The ultimate form of recycling. Fraunhofer IRB Verlag.
R2	Government-recognized certifications and standards encourage the adoption of remanufacturing practices.	4.253	0.727	0.912	3.600	Sundin, E., & Bras, B. (2005). Making functional sales environmentally and economically beneficial through product remanufacturing. Journal of Cleaner Production, 13(9), 913–925. https://doi.org/10.1016/j.jclepro.2004.04.006
R3	Government policy frameworks enhance consumer confidence in remanufactured products.	4.190	0.748	0.945	4.730	Hatcher, G. D., Ijomah, W. L., & Windmill, J. F. (2011). Design for remanufacture: A literature review and future research needs. Journal of Cleaner Production, 19(17–18), 2004–2014. https://doi.org/10.1016/j.jclepro.2011.06.019
R4	Government laws and regulations directly influence the growth and acceptance of the remanufacturing industry.	4.242	0.754	0.885	3.053	Gray, C., & Charter, M. (2007). Remanufacturing and product design: Designing for the 7th generation. The Centre for Sustainable Design, UK.
Quality Factor (Q)						
Q1	Remanufactured products provide quality that is equivalent or comparable to new products.	3.962	0.633	0.853	2.319	Subramoniam, R., Huisingh, D., & Chinnam, R. B. (2010). Remanufacturing for the automotive aftermarket–strategic factors. Journal of Cleaner Production, 18(13), 1163–1174. https://doi.org/10.1016/j.jclepro.2010.03.020

Abbr.	Measurement items	Mean	S.D.	Loading (>0.70)	Outer VIF (<5.00)	Source
Q2	Quality control is implemented throughout all stages of the remanufacturing process.	4.192	0.675	0.935	4.496	Juran, J. M., & Godfrey, A. B. (1999). Juran's quality handbook (5th ed.). McGraw-Hill.
Q3	Employees receive adequate training to effectively manage quality control during remanufacturing processes.	4.090	0.726	0.889	2.933	Ishikawa, K. (1985). What is total quality control? The Japanese way. Prentice Hall.
Q4	Traceability systems are in place to ensure the quality of remanufactured components.	4.162	0.660	0.893	3.614	Seitz, M. A. (2007). A critical assessment of motives for product recovery: The case of engine remanufacturing. Journal of Cleaner Production, 15(11–12), 1147–1157. https://doi.org/10.1016/j.jclepro.2006.05.029.
Information Factor (I)						
I1	Information related to remanufacturing processes is accurate and reliable.	4.067	0.698	0.925	3.283	Wang, R. Y., & Strong, D. M. (1996). Beyond accuracy: What data quality means to data consumers. Journal of Management Information Systems, 12(4), 5–33. https://doi.org/10.1080/07421222.1996.11518099
I2	Remanufacturing-related information is up-to-date and regularly updated.	3.998	0.783	0.918	3.072	Lee, Y. W., Strong, D. M., Kahn, B. K., & Wang, R. Y. (2002). AIMQ: A methodology for information quality assessment. Information & Management, 40(2), 133–146. https://doi.org/10.1016/S0378-7206(02)00043-5
I3	Information regarding costs, time, and resources in remanufacturing is systematically collected and utilized for analysis.	4.103	0.756	0.927	3.120	Guide, V. D. R., Jr., & Van Wassenhove, L. N. (2009). The evolution of closed-loop supply chain research. Operations Research, 57(1), 10–18. https://doi.org/10.1287/opre.1080.0628