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ORIGINAL RESEARCH

Economic Feasibility and Market Viability Analysis of Rehabilitation Exoskeleton Development for Stroke Recovery In Indonesia

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Abstract

Stroke is a major and growing cause of disability in Indonesia, creating significant health and economic burdens due to long-term mobility impairments. Rehabilitation exoskeletons are therefore needed to support mobility recovery and improve quality of life. An investment feasibility analysis of local exoskeleton production indicates strong financial viability across different implementation strategies. Factory rental offers the highest short-term returns, while factory construction and purchase provide long-term feasibility. Among these options, factory purchase is identified as the most strategic long-term investment, supported by cost efficiency, strong market demand, and the competitive advantage of locally produced exoskeletons compared to imported alternatives.

KEYWORDS:

Cost-Effective Healthcare; Economic Feasibility; Exoskeleton Technology; Market Demand; Stroke Rehabilitation

1 | INTRODUCTION

Stroke is one of the most significant non-communicable diseases affecting public health in Indonesia. Data from the Ministry of Health indicate that stroke ranks as the leading cause of long-term disability, with its incidence continuously increasing due to risk factors such as hypertension, diabetes, obesity, and unhealthy lifestyles. This condition has resulted in a high demand for effective rehabilitation services, particularly for patients experiencing motor impairments in the lower extremities, which hinder their independence in daily activities [1–3]. With advancements in medical technology, rehabilitation exoskeletons have emerged as an innovative solution with the potential to enhance the effectiveness of stroke recovery therapy. This technology is designed to support programmed movements to accelerate the restoration of patients' motor functions [4–6]. In Indonesia, the market for healthcare technology is expanding, driven by growing public awareness of health services and government initiatives aimed at achieving Sustainable Development Goal (SDG) 3, which focuses on increasing access to affordable and high-quality medical technology. Furthermore, the high incidence of stroke has created substantial demand for cost-effective and efficient rehabilitation devices.

Several previous studies have explored the development of rehabilitation exoskeletons, including research on brain-computer interface (BCI)-based hand exoskeletons that enable patients to control the device using brain signals, as well as studies on hand exoskeleton control mechanisms to enhance motor rehabilitation effectiveness [7–9]. Additionally, research on lower limb exoskeletons for home-based rehabilitation has demonstrated potential improvements in patient mobility, while feasibility studies on post-stroke rehabilitation robots have highlighted the importance of economic analysis in implementing this technology in Indonesia. Despite these studies, the development of rehabilitation exoskeletons in Indonesia still faces challenges, particularly in terms of economic viability and market sustainability. Therefore, this study introduces several novel contributions to advance this technology, including the integration of locally sourced technology at an affordable cost. By developing an exoskeleton utilizing local components and technology tailored to the needs of Indonesian patients, the study aims to produce a device with lower production costs without compromising quality and effectiveness [10, 11]. Additionally, this research conducts a comprehensive economic feasibility analysis, including cost-benefit evaluation, market projections, and commercialization strategies, to ensure that exoskeleton development is not only technically innovative but also financially sustainable in the Indonesian market [12–14].

Clinical evaluation and user feedback also form part of this study's novelty by conducting extensive clinical trials involving patients and medical professionals to assess the effectiveness, comfort, and ease of use of the exoskeleton [15–18]. These trials will collect valuable feedback to refine the design and functionality of the device. Furthermore, this research develops an inclusive business model, designing strategies to ensure broad accessibility across different socioeconomic groups, including financing schemes, partnerships with healthcare institutions, and effective distribution strategies. Although exoskeletons have been widely developed in advanced economies, their implementation in Indonesia requires a comprehensive feasibility study on economic viability and market sustainability [19, 20]. Thus, an in-depth analysis is essential to determine whether the development of this technology can be widely applied and sustained in the Indonesian market. This study will evaluate the financial aspects of rehabilitation exoskeletons using indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP). By understanding the economic prospects and market readiness in Indonesia, this research aims to provide a foundation for the development, production, and distribution of exoskeletons as a sustainable and innovative rehabilitation solution. This analysis is also expected to support strategic decision-making to ensure that this technology can compete with international products through its advantage of being more affordable while maintaining equivalent functionality.

2 | PREVIOUS RESEARCHES

Exoskeleton technology has been widely researched and developed in various fields, particularly in medical rehabilitation, military applications, and industrial support systems] [21, 22]. Previous studies have explored different aspects of exoskeleton development, including mechanical design, control systems, and clinical effectiveness [23, 24]. Biomechanical aspects of lower-limb exoskeletons, analyzing their impact on human gait and mobility [25, 26]. Similarly, the neuromechanical adaptations of users when utilizing powered exoskeletons for rehabilitation purposes . These studies highlight the potential benefits of exoskeleton technology in assisting individuals with mobility impairments [27, 28]. From an economic perspective, several studies have evaluated the feasibility of exoskeleton adoption in healthcare. The cost-effectiveness of wearable robotic devices for stroke rehabilitation, concluding that while exoskeletons offer significant functional improvements, their high production costs remain a major barrier to widespread implementation [29–31].In addition, the market trends and challenges associated with exoskeleton commercialization, emphasizing the need for affordable and accessible solutions to ensure broader adoption in rehabilitation centers. Despite the advancements in exoskeleton technology, several research gaps remain unaddressed. First, most existing studies primarily focus on technological innovations without adequately considering the economic feasibility and market potential of exoskeletons, particularly in developing countries [14]. Second, while clinical trials have demonstrated the effectiveness of exoskeletons in rehabilitation, there is limited research on user acceptance and accessibility, particularly in low-resource healthcare settings [5, 18]. Third, the development of cost-effective production models for exoskeletons remains a critical challenge, as current designs often rely on expensive components that hinder mass production and affordability [32–34]. The novelty of this study lies in its comprehensive approach, integrating economic feasibility analysis, market evaluation, and user-centered design principles to develop an exoskeleton model tailored for rehabilitation in Indonesia. By combining both qualitative and quantitative methodologies, this research aims to provide actionable insights for stakeholders, including healthcare providers, policymakers, and manufacturers, to promote the adoption of exoskeletons in rehabilitation. This study contributes to the field by proposing a sustainable business model that balances technological advancements with cost-efficiency, thereby addressing the research gaps identified in previous works.

3 | METHOD

This study uses a mixed-methods approach, combining quantitative and qualitative methodologies to assess the economic feasibility and market potential of rehabilitation exoskeleton technology in Indonesia. The study began by searching for journals related to exoskeleton technology, trends in medical rehabilitation, and previous studies that examine the technical, clinical, and economic aspects of the device. In addition, a search was conducted for journals and theories regarding the investment feasibility of new technologies in particular. Relevant literature is sourced from peer-reviewed scientific journals, industry reports, and government policies related to medical and rehabilitation technology. This study uses primary and secondary data to obtain the results of the investment feasibility of new technology, namely exoskeletons. Primary data were obtained through structured interviews with exoskeleton researchers at Telkom University regarding raw materials for production, costs, and production processes and the needs in producing one exoskeleton product, while secondary data were collected from industry reports, health statistics published by the Ministry of Health, and economic reports on investment in the medical technology sector.

The economic feasibility of the exoskeleton product is analyzed using key financial indicators, including Net Present Value (NPV) to determine investment feasibility, Internal Rate of Return (IRR) to evaluate investment profitability, and Payback Period (PP) to assess the time required for capital recovery. In addition, a cost-benefit analysis is conducted to compare production and development costs with anticipated financial and social benefits. A market assessment is conducted to compare with other similar products and evaluate Indonesia's readiness to adopt rehabilitation exoskeleton technology. This analysis includes potential demand and target markets based on stroke epidemiology data in Indonesia, the competitive advantages of domestically produced exoskeletons compared to imported alternatives.The detailed results of the economic feasibility analysis are presented in Table 4

The preliminary clinical evaluation of the Picobot rehabilitation exoskeleton was conducted with one post-stroke patient at Rumah Sakit Husada Utama, Surabaya. Ethical approval was obtained from the hospital's Ethics Committee (No. 22/KEP-RSHU/VII/2024), and informed consent was provided by the patient. The intervention protocol consisted of passive flexion training for 15 minutes, followed by gait training with the exoskeleton for 30 minutes per session. Training was administered twice per week for a total duration of two weeks (four sessions). Gait analysis was performed before and after the intervention, with stance phase percentage used as the primary outcome measure to assess changes in gait performance.

4 | RESULTS AND DISCUSSION

4.1 | Economic Feasibility

The Bill of Material (BOM) serves as a comprehensive list of all components required for the development of the rehabilitation exoskeleton. Each component is carefully selected based on its functionality, durability, and compatibility with the overall system. The BOM includes electrical components such as microcontrollers, sensors, actuators,

TABLE 1 Bill Of Material Exoskeleton

No.	Raw Material	Quantity	Unit Price (USD)	Total Cost (USD)
1	Microcontroller	1	$16.67	$16.67
2	Arduino Shield	1	$40.00	$40.00
3	Converter	1	$6.67	$6.67
4	Battery	1	$30.00	$30.00
5	Connector	1	$5.67	$5.67
6	Push Button	1	$1.00	$1.00
7	BLDC Motor (Actuator)	1	$833.33	$833.33
8	Ultrasonic Sensor	6	$10.00	$60.00
9	Polypropylene Sheet	1	$26.67	$26.67
10	Bolt	16	$0.53	$8.53
11	AWG 26 Cable (meters)	5	$0.13	$0.67
12	Stainless Steel (units)	3	$32.00	$96.00
13	Aluminum (units)	3	$7.67	$23.00
14	Plywood	1	$5.00	$5.00
15	Rubber	3	$6.67	$20.00
16	Synthetic Leather	3	$1.33	$4.00
17	Electrical Tape (rolls)	0.5	$0.40	$0.20
18	Shoe Glue (liters)	0.04	$9.33	$0.37
19	Solder (kg)	0.4	$4.67	$1.87
20	Shoelace	1	$0.10	$0.10
21	Sewing Thread (spools)	5	$3.67	$18.33
22	Shoelace Ring	2	$0.03	$0.07
23	Ethylene Vinyl Acetate (EVA) Sponge (sheets)	15	$6.40	$96.00
	Total			**$1,294.14**

and batteries, as well as structural materials like stainless steel, aluminum, and polymers to ensure mechanical stability and user comfort. The cost estimation in USD provides insights into the financial feasibility of the project, allowing for budget optimization and potential cost reductions through alternative sourcing strategies. The detailed breakdown in Table 1 serves as a reference for material procurement and production planning.

The financial investment required for the development and commercialization of rehabilitation exoskeletons is categorized into Capital Expenditure (CapEx) and Operational Expenditure (OpEx). CapEx includes costs associated with office assets, equipment, transportation, training, and intellectual property rights. These expenditures are essential for establishing the necessary infrastructure and ensuring regulatory compliance. On the other hand, OpEx consists of ongoing costs such as factory overhead and labor expenses, which are crucial for sustaining manufacturing operations and ensuring product quality. The estimation of these expenditures allows for financial forecasting and cost management strategies to enhance long-term project sustainability. The financial breakdown in Table 2 provides a structured overview of investment allocation, supporting decision-making processes in cost efficiency and resource optimization.

To ensure accurate financial projections, several key economic assumptions have been established based on reliable sources. These assumptions include inflation rates, tax obligations, minimum wage increments, marketing expenses, and insurance costs. The inflation rate and tax regulations significantly impact the financial feasibility of the project, while wage increments and labor-related expenses affect overall production costs. Additionally, insurance and social security contributions play a crucial role in mitigating risks associated with manufacturing and commercialization. The assumptions outlined in Table 3 provide a fundamental basis for financial modeling and sensitivity analysis, ensuring that potential risks and uncertainties are accounted for in investment decision-making.

TABLE 2 Cost to produce Exoskeleton

Capital Expenditure (CapEx)	
Description	Cost (USD)
Office Assets	$469.56
Equipment Assets	$1,480.26
Transportation Assets	$5,250.00
Training	$1,266.67
Copyright Registration	$660.00

Operational Expenditure (OpEx)	
Description	Cost (USD)
Factory Overhead Costs	$430,918.89
Labour Cost	$116,637.17

TABLE 3 Economic Assumption for Financial Modeling

Assumption	Value	Source
Inflation Rate	3,6%	Bolasalju, 2024
Tax Rate	30%	Alhanif, R. (n.d.), 2020
Minimum Wage Increase	6.13%	Arnani, M., 2023
Marketing Expenses	10.1%	Hafiz, M. P. A., 2023
Number of Remunerations	14	Mardiastuti, A., 2022
BPJS (Social Security) Expenses	11.27%	Nurhadi, M., 2024
Allianz Fire Insurance Insurance Expenses	0.152%	2024

TABLE 4 Economic Feasibility of Exoskeleton

Description		Build a Factory	Rent a Building	Buy a Factory
Net Present Value (NPV)		$754,944.62	$274,218.21	$1,224,777.17
Internal Rate of Return (IRR)		19%	49%	24%
Payback Period (PP)	Years	5.5	-1.4	4.8
	Months	65.6	-17	57.9

The financial evaluation of three investment strategies like building a factory, renting a building, and purchasing a factory. This strategy demonstrates significant differences in long-term financial viability. The analysis is based on key financial indicators: Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP). The financial feasibility analysis of the three investment alternatives demonstrates that all options are viable, but with varying degrees of profitability and payback speed. Building a factory generates a positive NPV of approximately Rp48.6 billion and an IRR of 37%, exceeding the 13% Minimum Attractive Rate of Return (MARR), with a payback period of 7.1 years, indicating long-term feasibility. Purchasing a factory also shows strong financial potential, with a positive NPV of about Rp53.7 billion, an IRR of 42%, and a payback period of 6.4 years, making it a relatively sound investment. However, renting a factory emerges as the most financially attractive option, yielding the highest NPV of around Rp96.9 billion, an extraordinary IRR of 887%, and an exceptionally fast payback period of only 1.8 months. These results suggest that, while all alternatives are financially feasible, renting a factory provides the most efficient and profitable strategy, especially for firms prioritizing rapid returns and reduced financial risk. The payback period (PP) results indicate that renting a building yields an immediate positive cash flow, as reflected in the negative value

TABLE 5 Comparative Analysis of Exoskeleton Pricing and Features

Brand / Model	**Country of Origin**	**Price (USD)**	**Primary Function**	**Target Users**
ReWalk 6.0	USA	$75,000–$85,000	Walking assistance for paraplegics	Individuals with spinal cord injuries
EksoNR	USA	$100,000–$140,000	Neurorehabilitation for stroke patients	Hospitals & rehabilitation centers
Indego Personal	USA	$98,000	Lower-limb mobility for disabled users	Personal & clinical use
Cyberdyne HAL	Japan	$90,000–$120,000	Assistive movement for neurological disorders	Hospitals & research institutions
textbfProposed Indonesian Exoskeleton	**Indonesia**	**$15,000–$20,000**	**Rehabilitation for stroke and mobility-impaired patients**	**Hospitals, clinics, and personal users**

of (-1.4 years or -17 months). This suggests that rental costs are lower in the short term, allowing for quicker financial returns. However, this approach has significant long-term drawbacks, including the absence of asset ownership, dependency on landlords, increased financial uncertainty due to potential rent fluctuations, and limited flexibility for facility customization or expansion. In contrast, both building and purchasing a factory require a higher initial investment but provide long-term benefits by securing ownership and reducing recurring costs. The PP for building a factory is 5.5 years (65.6 months), while purchasing requires 4.8 years (57.9 months), suggesting that purchasing a factory allows for a quicker return on investment. The Net Present Value (NPV) analysis further reinforces the importance of asset ownership. Renting a building results in the lowest NPV of $274,218.21, indicating that while it provides financial flexibility, it does not contribute to long-term wealth accumulation. In contrast, building a factory yields an NPV of $754,944.62, while purchasing a factory generates the highest NPV at $1,224,777.17.These findings suggest that purchasing a factory is the most profitable option over the long term, as it allows the company to build equity in its infrastructure while minimizing recurring operational costs. In terms of Internal Rate of Return (IRR), renting a building appears to be the most efficient option at 49%, followed by purchasing at 24% and building at 19%. The high IRR of the rental option is attributed to its low initial cost, which leads to a quick return on investment. However, IRR alone is not a sufficient metric for evaluating long-term financial sustainability, as it does not account for asset ownership and stability. A higher IRR in the short term does not necessarily translate into greater long-term benefits, making NPV and payback period equally critical in decision-making. Overall, the findings indicate that while renting a building appears financially attractive in the short term, it does not provide long-term sustainability, financial security, or asset accumulation. The most viable option for supporting the large-scale adoption of exoskeleton rehabilitation technology is purchasing a factory, which offers the highest NPV, a competitive IRR, and a reasonable payback period. By securing ownership of production facilities, the company can enhance operational efficiency, reduce long-term costs, and ensure financial stability, making it the most strategic choice for sustained growth in the exoskeleton industry.

4.2 | Market Viability

The market potential of Picobot in Indonesia is very large considering the high number of stroke patients who need rehabilitation. With a selling price of IDR 20.77 million per unit, Picobot is much cheaper than imported products of around IDR 39 million. Estimated sales reached 7,106 units per year, showing strong competitiveness in the domestic market. In terms of accessibility, these local products are more affordable for lower-middle class patients, while opening up wide market penetration opportunities.The detailed results of the Comparative Analysis of Exoskeleton Pricing and Features are presented in Table 5

The market viability of exoskeleton technology in Indonesia is largely influenced by affordability, accessibility, and competition with existing models. Currently, most exoskeletons available in the market are imported, leading to high costs due to import duties, logistics costs, and currency fluctuations. By being manufactured domestically, the proposed Indonesian exoskeleton offers a much more cost-effective alternative while maintaining comparable functionality. The average price of imported exoskeletons ranges between $75,000 and 140,000$, making them inaccessible to most individuals and small medical institutions. In contrast, locally developed exoskeletons are estimated to cost 15, 000*20,000, making them 75%-85% more affordable than their foreign counterparts. Despite the lower price, these devices retain key functionalities such as assisted mobility, muscle rehabilitation, and movement support for stroke patients and individuals with neuromuscular disorders. As shown in Figure 2 , the studied exoskeleton has similar structural components and functional capabilities to existing models, indicating its potential as a viable alternative. In addition, local production eliminates dependence on imports, reducing procurement time and costs associated with import taxes and shipping. In addition, there are several provisions, such as the level of domestic components (TKDN) that must be met by manufacturers. Another advantage of domestic production is the ability to customize the design to the needs of Indonesian patients, ensuring ergonomic compatibility, local interfaces, and adaptability based on user input. This product will be tailored to the anthropometric conditions of the Indonesian community. In addition, integration with BPJS Kesehatan and private insurance schemes can increase accessibility through subsidized prices and rental options. From all these factors, the proposed exoskeleton demonstrates strong market viability by offering a financially viable and technologically competitive solution. The combination of low production costs, reduced import dependence, and strategic alignment with Indonesia's healthcare infrastructure positions this technology as a high-impact innovation in rehabilitation and assistive medical devices. Investing in domestic production and long-term asset ownership, such as factory establishment, will further enhance the sustainability and scalability of this initiative, ensuring widespread adoption and economic benefits for Indonesia's growing medical technology sector.

4.3 | Clinical Evaluation

Picobot as a stroke rehabilitation tool has reached the prototype stage with the integration of FSR sensor technology and application-based control systems. Technically, this device is able to help restore mobility in stroke patients, but it still requires further development, clinical trials, and compliance with medical regulatory standards before mass production. Production infrastructure can be run either with the option of building, renting, or purchasing a factory, with capacity, efficiency, and sustainability considerations in mind. The short-term application of Picobot showed promising improvements in gait performance. Gait analysis revealed that the patient's stance phase increased from 11% at baseline to 14% after two weeks of intervention, representing a 3 percentage point improvement (27.3% relative increase). This suggests enhanced stability and weight-bearing ability during walking. The observed increase in stance phase indicates a potential positive impact of the exoskeleton in improving motor control and gait pattern for stroke patients with mobility impairments. Although the intervention period was relatively short and involved limited training sessions, the result demonstrates early signs of functional improvement. These findings are in line with previous studies reporting that robotic exoskeleton-assisted gait training can contribute to motor recovery and functional ambulation in post-stroke rehabilitation.

However, the evaluation from Figure 1 is limited to a single case study with a short follow-up period, and no comparison was made to conventional physiotherapy or other rehabilitation approaches. Further studies with larger sample sizes, longer training durations, and additional outcome measures (e.g., gait speed, step length, symmetry index, functional ambulation categories) are required to validate the effectiveness of Picobot as a rehabilitation tool. Nevertheless, this preliminary evidence highlights the feasibility of integrating locally developed exoskeleton technology into clinical rehabilitation practice in Indonesia.

5 | CONCLUSION

This research has been completed and give a conclusion that the development and production of a locally manufactured rehabilitation exoskeleton in Indonesia are considered both financially feasible and clinically promising. From an investment perspective, all production alternatives constructing, renting, or purchasing a factory—were found to be viable, with renting providing the fastest short-term return, while ownership through construction or purchase was assessed as more sustainable in the long term due to asset security and reduced recurring costs. Clinically, short-term application of the Picobot was demonstrated to improve gait performance, with a relative increase of 27.3% in

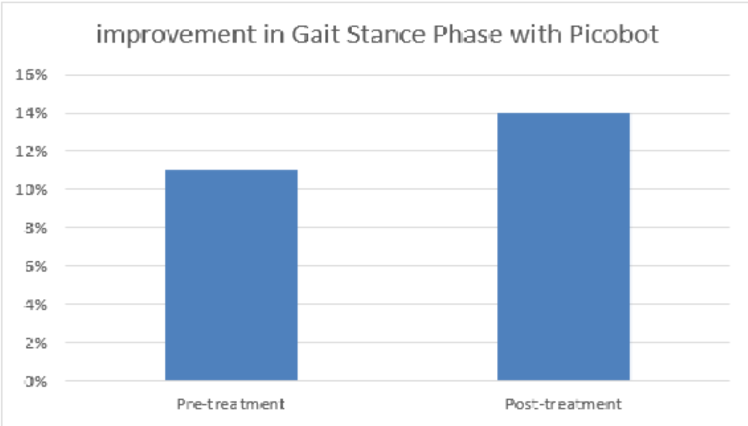

FIGURE 1 Clinical Evaluation of Exoskeleto

FIGURE 2 Picobot Exoskeleton

the stance phase, indicating potential enhancement of motor control and functional recovery in post-stroke patients. From a market standpoint, domestic production was shown to overcome barriers of affordability and accessibility, with projected costs at only 15–25% of imported models while retaining essential rehabilitation functions. Therefore, it is concluded that local production of rehabilitation exoskeletons is strategically advantageous for strengthening industrial independence, expanding healthcare accessibility, and supporting the transformation of rehabilitation services in Indonesia.

CREDIT

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