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Construction and Optimization of Investment Return Model for Logistics Robots in Warehouse Automation Upgrade

Jinhao Lao *, Wanping Du

School of Economics and Management, Southwest Petroleum University, Chengdu 610500, China
*Corresponding Author: 895114314@qq.com

ABSTRACT

With the rapid development of the logistics industry, warehouse automation upgrades have become crucial for improving logistics efficiency and competitiveness. As a key component of warehouse automation, the return on investment (ROI) of logistics robots has attracted considerable attention. This paper aims to construct an ROI model for logistics robots in the context of warehouse automation upgrades, and through optimization analysis of the model, to provide a scientific basis for enterprises in making investment decisions regarding logistics robots. First, it elaborates on the background of warehouse automation upgrades and the current state of logistics robot applications, and analyzes the importance of constructing an ROI model. Next, it introduces the model construction process in detail, including cost analysis, benefit analysis, and the assumptions and simplifications of the model. Then, the model is validated and analyzed using a real case study, and the key factors affecting the ROI are discussed. Finally, based on the results of the model analysis, strategies and recommendations for optimizing the ROI of logistics robots are proposed, offering a reference for warehouse automation upgrades in warehousing enterprises.

KEYWORDS

Warehouse automation; Logistics robots; Return on investment (ROI); Model optimization

1. INTRODUCTION

1.1. Research Background

With the rapid growth of e-commerce, the business volume of the logistics industry has experienced explosive expansion. Traditional manual warehousing models can no longer meet the demand for efficient and accurate logistics services, making warehouse automation upgrades an inevitable trend. As one of the core equipment components of warehouse automation, logistics robots offer advantages such as high efficiency, flexibility, and precision. They can significantly improve warehousing operation efficiency, reduce labor costs, and enhance inventory management. However, the initial investment in logistics robots is substantial, and enterprises need a scientific and reasonable evaluation of the return on investment (ROI) when making investment decisions.

1.2. Research Purpose and Significance

This study aims to construct an accurate and practical ROI model for logistics robots, assisting enterprises in comprehensively evaluating the economic benefits of logistics robot investments during the warehouse automation upgrade process, thereby providing strong support for investment decision-making. Furthermore, through optimization analysis of the model, this study explores the key factors affecting ROI and proposes corresponding optimization strategies, helping enterprises improve the ROI of logistics robots and achieve sustainable development in warehouse automation.

1.3. Literature Review

1.3.1. Research on Warehouse Automation

Scholars both domestically and internationally have conducted extensive and in-depth research on warehouse automation. In terms of warehouse automation system planning, Zhong Yanni (2021) introduced the main components, process flow, equipment configuration, and key technologies of automated logistics systems, providing a reference for the automated warehouse construction of other enterprises [1]. Regarding the application of warehouse automation technologies, Bai Guangli (2023) investigated the use of equipment such as automated storage and retrieval systems (AS/RS), automated guided vehicles (AGVs), and stacker cranes in warehousing operations, analyzing their roles in improving efficiency and accuracy [2]. Zhang Xiaojun (2021) introduced the development stages of automation technology in China's warehousing sector and the current state of warehouse automation in China's logistics centers, and made reasonable predictions about the future development trends of warehouse automation in China's logistics centers [3]. Chen Yan (2024) studied the application of intelligent warehousing technologies, comparing traditional barcode systems with RFID systems and revealing the advantages of RFID in terms of accuracy, reliability, and data collection speed [4].

1.3.2. Research on Logistics Robots

As an emerging technology in warehouse automation, logistics robots have drawn increasing attention from scholars. Li Bingyi (2018) provided a systematic review of the classification, working principles, and application status of logistics robots, pointing out their broad application prospects in warehousing operations [5]. Yan Yan et al. (2021) introduced the types of warehousing logistics robots currently used in China, identified the problems encountered in their development, and proposed corresponding countermeasures [6]. Huang Huaisong (2018) studied scheduling algorithms for logistics robots, aiming to improve their operational efficiency and coordination through optimized scheduling strategies [7]. Zhang Jie (2025) addressed the problem of low grasping efficiency of industrial robots in warehouse automation scenarios by constructing a neural network algorithm model, integrating image and sensor data for feature extraction and fusion, and optimizing model parameters; the optimized algorithm improved grasping success rate, precision, and adaptability [8]. Kang Chengbo et al. (2020) proposed an improved bidirectional search A* algorithm based on the standard A* algorithm for the path planning of logistics robots [9].

1.3.3. Research on ROI Models

ROI models play a significant role in corporate investment decision-making. Traditional ROI models primarily include the Net Present Value (NPV) method, the Internal Rate of Return (IRR) method, and the payback period method. Yang Zhuoyi (2022) constructed an ROI model for power grid infrastructure investment, predicting the factors involved in measuring the returns on such investments, thereby enabling power grid companies to promptly understand the returns on their infrastructure investments [10]. Wang Zhen et al. (2019) constructed an ERP-based ROI model for the fleets of small and medium-sized airlines, using the NPV method to build the model and analyze the investment and operation situations of these airlines, providing a reference for other companies [11].

1.4. Summary of Current Research

Although considerable achievements have been made in research on warehouse automation, logistics robots, and ROI models, studies specifically focusing on the ROI model for logistics robots in the context of warehouse automation upgrades remain relatively scarce. Most existing research focuses on the technical applications and scheduling algorithms of logistics robots, while comprehensive evaluation and model optimization of their ROI are still insufficient. Therefore, it is necessary for this study to construct an ROI model specifically tailored to logistics robots in warehouse automation upgrades and to conduct an optimization analysis on the model.

2. CONSTRUCTION OF THE ROI MODEL FOR LOGISTICS ROBOTS

2.1. Cost Analysis

2.1.1. Acquisition Cost

The acquisition cost of logistics robots includes the price of the robot units themselves, the cost of supporting equipment (such as charging stations, navigation devices, etc.), and system integration expenses. Prices of logistics robots vary significantly depending on their types, brands, and functions, and enterprises need to select appropriate products based on their own needs and budgets.

2.1.2. Installation and Commissioning Cost

The installation and commissioning cost mainly comprises the expenses for robot installation, commissioning, and the deployment of related software systems. This portion of the cost is generally related to the number of robots, their complexity, and the installation environment.

2.1.3. Operation and Maintenance Cost

The operation and maintenance cost includes daily maintenance expenses, spare parts replacement costs, energy consumption costs, and labor management costs for the robots. Although the operation and maintenance cost of logistics robots is relatively low, regular maintenance is necessary to ensure their normal operation.

2.1.4. Training Cost

To enable employees to proficiently operate and manage logistics robots, enterprises need to provide training for their staff. Training costs include the expenses for compiling training materials, instructor fees, as well as the wages and benefits of employees during the training period.

2.2. Benefit Analysis

2.2.1. Direct Economic Benefits

(1) Labor Cost Savings

Logistics robots can replace some manual operations, reducing the demand for labor and thereby lowering labor cost expenditures.

(2) Operational Efficiency Improvement

With their efficient and accurate operational capabilities, logistics robots can improve warehousing operation efficiency, shorten order processing time, and increase inventory turnover rates, thus leading to growth in sales revenue.

(3) Increased Space Utilization

Logistics robots can achieve high-density storage and precise handling, improving warehouse space utilization and reducing warehouse rental or construction costs.

2.2.2. Indirect Economic Benefits

(1) Improved Inventory Management

Logistics robots can obtain real-time inventory information and achieve precise inventory management, reducing the risks of inventory overstocking and stockouts, and improving the efficiency of capital utilization.

(2) Enhanced Corporate Image

Warehouse automation upgrades and the application of logistics robots can enhance the modern image of an enterprise, increase customer trust and satisfaction, and thereby bring more business opportunities.

2.2.3. Strategic Benefits

(1) Enhancing Enterprise Competitiveness

Through warehouse automation upgrades and the application of logistics robots, enterprises can improve the quality and efficiency of their logistics services and reduce costs, thereby gaining a competitive advantage in the fierce market competition.

(2) Adapting to Future Development Needs

With the continuous development of the logistics industry and ongoing technological advancement, logistics robots have broad application prospects. By adopting logistics robots early, enterprises can better adapt to future market changes and development needs.

2.3. Model Assumptions and Simplifications

To facilitate model construction and calculation, this study makes the following assumptions and simplifications:

It is assumed that the service life of the logistics robots is n years, during which their performance and efficiency remain unchanged.

It is assumed that the enterprise's operating revenue and costs maintain steady growth during the calculation period, with growth rates of r_1 and r_2, respectively.

The impact of factors such as inflation on the return on investment is ignored.

The indirect economic benefits and strategic benefits of the logistics robots are quantified and incorporated into the investment return calculation.

2.4. ROI Calculation Model

There are various methods for analyzing investment returns, such as the payback period method and the net present value (NPV) method. Among them, the NPV method is the most commonly used and scientifically rigorous approach. The NPV method is a technique for evaluating investment proposals. Its essence lies in calculating the difference between the present values of future net cash flows over the return period (i.e., the net present value) and judging the merits of the project investment proposal based on the magnitude of the NPV. Generally, it is required that the NPV over the investment return period is positive [12, 13]. Based on the above cost analysis and benefit analysis, the NPV-based ROI calculation model for logistics robots is constructed as follows:

$$NPV = \sum_{t=0}^{n} \frac{CI_t - CO_t}{(1+r)^t} - I_0 \tag{1}$$

Where: NPV — Net Present Value;

CI_t — Cash inflow in year t, including labor cost savings, sales revenue growth from improved operational efficiency, cost savings from increased space utilization, and the quantified values of indirect economic benefits and strategic benefits;

CO_t — Cash outflow in year t, including the apportioned values of acquisition cost, installation and commissioning cost, operation and maintenance cost, and training cost;

r — Discount rate;

n — Service life of the logistics robots;

I_0 — Initial investment amount.

If $NPV \geq 0$, the investment proposal is feasible; if $NPV < 0$, the investment proposal is not feasible.

2.5. Sensitivity Analysis

To analyze the degree of influence of various factors on the return on investment of logistics robots, a sensitivity analysis is conducted. Key factors such as acquisition cost, operation and maintenance cost, labor cost savings rate, and operational efficiency improvement rate are selected as sensitivity analysis variables, and the impact of their changes on the net present value (NPV) is calculated separately. Through the sensitivity analysis, the key factors affecting the return on investment can be identified, providing a reference for the enterprise's investment decision-making and risk management.

3. EMPIRICAL ANALYSIS

3.1. Case Company Profile

Company A, an e-commerce warehousing enterprise, is selected as the case study subject. The company is primarily engaged in the warehousing and distribution of e-commerce goods, with an existing warehouse area of 5,000 m^2 and a manual sorting team of 120 workers. With the continuous growth of business volume, the traditional manual warehousing model can no longer meet its demands for efficient and accurate logistics services. To improve warehousing operation efficiency and service quality, the company plans to undertake a warehouse automation upgrade by introducing 50 AGV logistics robots.

3.2. Data Collection and Organization

Relevant data on the logistics robot investment of the case company were obtained through public online sources. These data include the acquisition cost, installation and commissioning cost, operation and maintenance cost, training cost, labor cost, operational efficiency, and space utilization rate of the logistics robots. The cost data are presented in Tables 1 and 2. Additionally, based on the company's historical financial data and market development trends, future revenue and cost growth are forecasted, with the benefit data shown in Tables 3 and 4.

Table 1. Initial investment cost

cost item	Calculation method	Amount (RMB10000)
purchase cost	50 AGV robots (RMB 80,000 per unit) + charging piles (RMB 200,000) + navigation system (RMB 300,000).	450
Installation and debugging costs	8% of the acquisition cost	36
Training cost	5 training sessions (each with 10 participants × RMB 5,000 per person) + teaching materials costing RMB 50,000.	30
Total initial investment		516

Table 2. Annual operating costs

revenue item	Amount in the first year	annual growth rate	Computational Logic
Operation and maintenance costs	25	5%	This includes parts replacement costs of RMB 150,000, energy consumption of 50 units × RMB 1,000 per unit per year (amounting to RMB 50,000), and labor management costs of RMB 50,000.
Software upgrade cost	8	3%	Annual maintenance and upgrade costs for the Warehouse Management System (WMS).
Total annual operating costs	33	-	Subsequently, the values rise in accordance with their respective growth rates.

Table 3. Direct economic benefits

revenue item	Amount in the first year	annual growth rate	Computational Logic
Labor cost savings	240	-	By replacing 80 sorting workers, each with an average annual salary of RMB 30,000, the annual cost savings amount to 80×30,000 = RMB 2.4 million.
Improving homework efficiency	180	10%	The annual sales revenue increase, derived from the growth in order processing volume from 12,000 to 18,000 orders per day, is calculated as (18,000 - 12,000) orders/day × 300 days × RMB 10/order.
Space utilization efficiency improvement	30	5%	Through the implementation of high-density storage, the required leased area is reduced by 1,000 square metres, yielding annual rental savings of 1,000 m^2 × RMB 10 per square metre per month × 12 months = RMB 120,000. In addition, racking modification costs are reduced by RMB 180,000.
Total direct benefits	450	-	

Table 4. Indirect and strategic benefits

revenue item	Amount in the first year	annual growth rate	Computational Logic
Inventory management optimization	20	8%	Inventory overstock and stockout losses are reduced, with the benefit measured at 1% of the total inventory value (based on an average annual inventory of RMB 20 million).
Corporate image premium	15	10%	The increase in annual order revenue attributable to new customers is estimated at 1% of the existing revenue base.
Total indirect benefits	35		

3.3. Model Calculation and Result Analysis

The collected data are substituted into the ROI calculation model, and indicators such as the net present value (NPV), internal rate of return (IRR), and payback period of the logistics robot investment are calculated. The calculation results are shown in Table 5.

Table 5. Model calculation results

year	cash inflow	cash outflow	Net cash flow
0	0	516	-516
1	485	33	452
2	533	34.65	498.35
3	586.3	36.38	550.02
4	645.93	38.19	607.74
5	712.52	40.10	672.42

Based on the table data, the net present value is calculated as follows:

$$NPV = -516 + \frac{452}{(1+0.08)^1} + \frac{489.35}{(1+0.08)^2} + \frac{550.02}{(1+0.08)^3} + \frac{607.74}{(1+0.08)^4} + \frac{672.42}{(1+0.08)^5}$$
$$\approx 1628.5\left(RMB10000\right)$$

The above is the investment return analysis for the logistics robot solution of E-commerce Warehouse Enterprise A. The results show that the net present value of cash flows generated by 50 logistics robots over their useful life is approximately 16.285 million RMB, with a payback period of 2 years, indicating that the investment plan is economically feasible.

3.4. Sensitivity Analysis

Taking the data of the first year as an example, a sensitivity analysis is conducted on the model variables, and the results are shown in Table 6.

Table 6. Sensitivity analysis

variable	percentage change	NPV change (RMB 10,000)	conclusion
purchase cost	+10%	-45	A 10% rise in acquisition cost leads to a roughly 2.76% decline in NPV, underscoring the need to rigorously control equipment procurement prices.
Labor cost savings rate	-5%	-24	A 5% decline in the labor cost savings rate leads to a roughly 1.47% reduction in NPV, underscoring the need to ensure effective personnel optimization.
Efficiency improvement rate of homework	+10%	+48	Enhancements in operational efficiency can generate substantial revenue gains, and it is advisable to further unlock potential through ongoing technological optimization.

Through the sensitivity analysis, it is found that the acquisition cost and the labor cost savings rate are the factors that have a greater impact on the investment return of logistics robots. When the acquisition cost decreases by a certain percentage or the labor cost savings rate increases by a certain percentage, the net present value will increase significantly; conversely, when the acquisition cost rises or the labor cost savings rate declines, the net present value will decrease notably. Therefore, when making investment decisions regarding logistics robots, enterprises should pay close attention to controlling the acquisition cost and ensuring the effectiveness of labor cost savings.

4. OPTIMIZATION OF THE INVESTMENT RETURN MODEL FOR LOGISTICS ROBOTS

4.1. Cost Control Strategies

Rational planning of procurement quantity: Determine the number of logistics robots to purchase based on the enterprise's actual needs and business development plans, so as to avoid over-investment that leads to equipment idleness and resource waste.

Optimizing supply chain management: Establish long-term and stable partnerships with suppliers to secure more favorable purchase prices and payment terms. At the same time, strengthen supply chain management to reduce procurement costs and inventory costs.

Improving equipment utilization: Optimize warehouse layout and operational processes, rationally assign work tasks to logistics robots, increase equipment utilization, and lower unit operating costs.

4.2. Revenue Enhancement Strategies

Expanding application scenarios: Beyond traditional warehousing, handling, and sorting operations, explore the use of logistics robots in other logistics links, such as packaging, loading and unloading, etc., to further leverage their advantages and increase revenue.

Strengthening integration with other systems: Integrate logistics robots with the enterprise's Warehouse Management System (WMS), Enterprise Resource Planning (ERP) system, and others to enable information sharing and collaborative operations, thereby improving overall operational efficiency and effectiveness.

Developing value-added services: Leverage the technological advantages of logistics robots to provide customers with customized logistics services, such as tailored packaging and precision delivery, thereby increasing service added value and boosting revenue levels.

4.3. Risk Assessment and Countermeasures

Technology risk assessment and response: Monitor the development trends and upgrade cycles of logistics robot technology; choose products with mature technology and high stability. Meanwhile, strengthen internal R&D and innovation to enhance the enterprise's independent technical capabilities and mitigate technology risks.

Market risk assessment and response: Closely track market dynamics and competitors' moves, and adjust business strategies and investment decisions in a timely manner. Enhance market development and marketing efforts to increase market share and competitiveness.

Operational risk assessment and response: Establish a sound operational management mechanism and maintenance system for logistics robots; strengthen personnel training and management to ensure normal equipment operation and work safety. Develop contingency plans to cope with possible equipment failures and emergencies.

4.4. Model Optimization Based on New Technologies

With the continuous development and application of new technologies such as artificial intelligence (AI), big data, and the Internet of Things (IoT), new opportunities have emerged for optimizing the investment return model of logistics robots. Enterprises can leverage these technologies to achieve real-time monitoring and data analysis of logistics robots, optimize scheduling algorithms and operational processes, and enhance the intelligence level and operational efficiency of the equipment. At the same time, combined with big data analytics, enterprises can more accurately forecast market demand and cost changes, providing a more scientific basis for investment decisions. For example, IoT technology enables remote monitoring and fault diagnosis of logistics robots, allowing timely detection and resolution of issues, thereby reducing operation and maintenance costs; AI technology can be used to optimize scheduling algorithms, improve the collaborative efficiency of logistics robots, and further increase revenues.

5. CONCLUSION

This study constructs an investment return model for logistics robots in warehouse automation upgrades, and through empirical analysis and optimisation research, draws several important conclusions. First, investment in logistics robots offers considerable economic benefits and strategic value. The direct economic benefits are derived from labour cost savings, operational efficiency improvements, and enhanced space utilisation, while the indirect economic and strategic benefits include better inventory management and an improved corporate image, all of which can significantly strengthen the enterprise's competitiveness and profitability. Second, acquisition cost and the labour cost savings rate are the key factors affecting the investment return of logistics robots, and enterprises should give priority to controlling and optimising these two factors when making investment decisions. In addition, through the implementation of cost control strategies, revenue enhancement strategies, risk assessment and countermeasures, and model optimisation based on new technologies, the return on investment of logistics robots can be effectively increased while investment risks are reduced.

Nevertheless, this study has certain limitations. For example, during model construction, some data may not have been sufficiently accurate, which affects the model's precision; in the empirical analysis, only one case enterprise was selected for study, so the conclusions may lack generalisability. To address these issues, future research can be improved in the following aspects: further refine the investment return model by collecting more accurate data, optimising model parameters and calculation methods, and enhancing the model's accuracy and reliability, while also incorporating additional influencing factors such as policy environment and market demand changes to make the model more closely reflect real-world conditions; expand the scope of empirical research by selecting warehousing enterprises of different types and scales for empirical analysis to verify the model's applicability and generalisability, and by comparing cases across different enterprises to summarise lessons learned and provide more targeted investment decision recommendations for enterprises; and conduct in-depth research on the application of new technologies in optimising logistics robot investment returns. As emerging technologies such as artificial intelligence, big data, and the Internet of Things continue to develop, their application in the logistics robot field is becoming increasingly widespread. Future research can explore in depth how these new technologies can be integrated with the investment return model to achieve more precise investment decisions and operational management.

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